Passage and Survival of Juvenile Chinook Salmon Migrating from the Snake River Basin

Proceedings of a Technical Workshop
University of Idaho
February 26-28, 1992

Presented by

Idaho Chapter of the American Fisheries Society
Idaho Water Resources Research Institute, University of Idaho
Idaho Cooperative Fish and Wildlife Research Unit
College of Forestry, Wildlife and Range Resources, University of Idaho
Western Division of the American Fisheries Society

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Overview

Impetus for the Passage and Survival Workshop was provided by the recent "threatened" listing of Snake River spring and summer chinook salmon stocks under the provisions of the Endangered Species Act. The listing initiated a region-wide debate over remedial measures for restoration of the threatened stocks. The intent of the Workshop organizers was to provide a forum for discussion of two fundamental questions: "how adequate is the available technical information on factors affecting the passage and survival of juvenile chinook salmon migrating from the Snake River basin?" and "what information is needed but not now available?" These questions were addressed at length during the two and one-half day workshop, which was attended by many of the researchers most familiar with existing information on salmonid migration, passage and survival in the Snake River basin. A selective (and necessarily subjective) summary of some of the Workshop highlights is provided below.

As a consequence of depressed natural production and steadily increasing hatchery production of chinook salmon, 90 to 95% of the juvenile chinook salmon passing the dams on the Snake River are believed to be of hatchery origin. For this reason, information collected in recent years on the in-river migration and survival of juvenile chinook salmon largely reflects the performance of hatchery stocks, rather than the wild fish stocks with which the Endangered Species Act is concerned. The development of the Passive Integrated Transponder (PIT) tag has made possible the collection of information on wild fish, which can be tagged in the field and easily identified when they arrive at downstream dams.

New information was presented on the migration timing of wild spring and summer chinook salmon tagged with PIT tags in Idaho and Oregon headwater streams. Wild spring chinook salmon arrived at the Snake River dams over a more protracted period and 1 to 6 weeks later than hatchery fish (Achord et al.; Keifer). Similar observations were reported on the migration timing of natural and hatchery-reared fall chinook: natural subyearlings migrated primarily from early July through mid-August, about 1 month later than hatchery subyearlings and 2 to 3 months later than hatchery yearlings (Connor et al.)

Several papers evaluated the relationship between Snake River flows and the migration rates and survival of juvenile salmon. The migration rates of PIT-tagged chinook salmon between trap sites on the Snake and Clearwater Rivers near their confluence at Lewiston to the first downstream dam, Lower Granite, increased with increasing flow (Buettner). Analysis of historical data indicated that water particle travel times from the head of Lower Granite Reservoir to Bonneville Dam have increased 6- to 15-fold as a consequence of dam construction on the Snake and Columbia Rivers, and that in-river survival rates and smolt-to-adult return rates have been adversely affected by decreased flows and increased water particle travel times (Petrosky).

The migratory behavior of juvenile chinook salmon that are physiologically prepared to move from fresh to salt water (smolts) is much less influenced by river flow than the migratory behavior of incompletely smolt-transformed fish (Beeman and Rondorf). Experimental acceleration of the rate of smolt-transformation of chinook salmon reared at Dworshak Hatchery increased the migration rate after release and also the recovery rate at Lower Granite Dam (Muir). The smolt transformation of hatchery-reared fish should be monitored so that they are not released before they are ready to migrate (Beeman and Rondorf).

Large numbers of juvenile chinook salmon are sampled annually from hatcheries, rearing streams or trapping stations in Idaho and Oregon and PIT-tagged or freeze-branded. Estimation of the number of tagged fish surviving to reach Snake River dams requires that assumptions be made about the proportions of fish that are guided into bypasses (where they can be interrogated for recognition of PIT tags or subsampled for recognition of freeze brands), or passed through turbines or over spillways. Therefore, estimates of survival based on tag recovery are imprecise, but indicate the magnitude of losses. The recovery at downstream dams of migrating spring chinook salmon smolts that were captured, PIT-tagged and released near Lewiston varied from 54 to 68% in the years 1988 to 1991 (Buettner). Similarly, less than 50% of freeze-branded fish released from two Oregon hatcheries reached Lower Granite dam in the years 1987 to 1991; it was suggested that these losses contributed significantly to poor adult return rates (Carmichael et al.). The causes and locations of these losses are unknown: possibilities discussed at the workshop included excessive competition for food among large numbers of migrating hatchery fish, cessation of migration (but no evidence was found for residualization of chinook salmon in Lower Granite Reservoir during a 4-year sampling effort [Bennett]), predation, and disease.

Bacterial kidney disease (BKD), a chronic disease that causes mortality during both the freshwater and saltwater life-phases of chinook salmon, was reported to be common in both hatchery and wild stocks of chinook salmon (Pascho). Most migrating smolts arriving at Lower Granite Dam were also found to be infected (Elliott). The microorganism responsible for BKD was isolated from river water and from fish collection raceways and fish transport barges, and water-borne transmission to uninfected fish was shown in field live-box tests and laboratory challenge experiments (Elliott). Further research is needed to determine if BKD-caused mortality is a major factor in the poor smolt-to-adult return rates of both transported and nontransported smolts. Other diseases in addition to BKD may reduce the survival of hatchery fish after release, but little information is available on the prevalence of diseases and parasites in outmigrating juvenile salmonids (Groberg and Onjukka).

Much of the discussion at the workshop dealt with the application and appropriateness of models correlating smolt-to-adult return rates with Snake River flows. The models use data collected from 1970 to 1980 (the regionally standardized data set, excluding 1971), or in some cases include additional data from the late 1960s and the 1980s. The physical structures at the dams (trash racks, travelling screens and bypass systems, structures to reduce gas supersaturation, etc.) have been continuously modified over the years to reduce deleterious effects on migrating salmonids (Matthews). The composition of the fish populations has changed also, from largely wild in the 1960s to largely hatchery-reared at present. Because of these changes, the applicability of survival data from the earlier years to modelling of the present situation is questionable. Examples given at the workshop of conditions believed to have reduced the survival of migrating smolts in the 1970s (but since corrected) included major but inadequately documented effects of gas supersaturation in the early 1970s (Bouck and Ebel, Petrosky), problems with slotted gates at Lower Monumental and Little Goose Dams in 1972 (Petrosky), problems with newly installed submersible travelling screens and vertical barrier screens at Little Goose Dam in 1973 (Giorgi), and accumulation of massive quantities of debris at Lower Granite Dam in 1977 through 1981 (Matthews). Questions about the present-day applicability of data on survival of smolts outmigrating in 1973 and 1977 are especially cautionary, because these are the only two years of extreme low flow in the regionally standardized data set.

Several papers discussed new methodologies and technologies for guiding (Grabowski and Brege), bypassing, and nonlethal monitoring (Stansell) of fish at the dams. Bypasses have generally been assumed to be a relatively safe alternative to turbine passage, but this is not true of the one bypass studied to date (Dawley et al.). New criteria for bypass siting, based on the use of hydraulic scale models to evaluate water flow patterns and velocities below dams under various flow conditions (Peters) and on laboratory studies of the physiology and behavior of predatory fish (Mesa et al.), have been developed to reduce the exposure of bypassed smolts to predatory fish.

Predation by northern squawfish has been identified as a major cause of mortality for migrating juvenile salmonids in some reaches of the Columbia River. Efforts are underway to reduce the size of squawfish populations, but the response of squawfish populations to exploitation and the response of other predator populations to reduced abundances of squawfish are presently uncertain (Ward and Poe).

Although data are available on the survival of smolts through the dam and reservoir complex under different flow conditions, little information is available on the mortality associated with specific dams or reservoirs (Giorgi). In addition, the consequences of alternative management actions to move fish through or around the dams are inadequately understood; the relative survival rates of spilled, bypassed and transported fish below Bonneville dam, in the estuary and ocean, are unknown (McConnaha). A number of studies have, however, compared the adult return rates of groups of spring chinook smolts marked and transported below Bonneville dam in trucks or barges with return rates of control fish marked and returned to the river (control fish may have subsequently experienced spill, bypass, turbine passage, or transportation from a downstream dam before reaching the estuary). Findings from these transportation studies were reviewed (Matthews). In the two most recent trials, the survival of transported fish was 160% (1986) and 250% (1989) that of control fish. A model of the relationship between flow and survival of transported and nontransported fish was developed using the assumption that transportation benefits were as indicated by the 1986 transportation test; it indicated that transportation of spring chinook smolts from Lower Granite Dam would have been beneficial under the spring flow conditions prevailing in 45 of the past 50 years (McConnaha).

Gas supersaturation caused by entrainment of air into water spilled over dams frequently caused gas-bubble disease in migrating juvenile and adult salmonids during the early 1970s. The problem was largely eliminated by changes in dam operating procedures and by the installation of deflectors in spillways. Because the effectiveness of spillway deflectors is reduced at higher spillway flows and by lower tailwater elevations, gas supersaturation may again be a problem under proposed drawdown conditions in Snake River reservoirs (Bouck and Ebel).

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Use of PIT Tags to Monitor the Smolt Migrations of Spring and Summer Chinook Salmon Stocks in the Snake River Basin, 1989-91

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Introduction

In most years since 1966, migrations of Snake River yearling chinook salmon *Oncorhynchus tshawytscha* have been monitored by downstream recoveries of freeze-branded fish previously released from upstream hatcheries, scoop traps, turbine intake gatewells, or dam bypass systems (Bentley and Raymond 1968; Park and Ebel 1974; Raymond 1974, 1979; Ebel 1980). The brands identified groups of fish, but not individuals.

Laboratory tests conducted by the National Marine Fisheries Service (NMFS) from 1984 through 1986 demonstrated the potential of using the Passive Integrated Transponder (PIT) tag for identifying individual salmonids (Prentice et al. 1990b).

We began using PIT tags in 1988 to examine the migratory behavior, particularly the run-timing at dams, of wild stocks of chinook salmon smolts in the Snake River Basin. This paper presents results of PIT-tag studies with wild and hatchery spring and summer chinook salmon marked as parr and subsequently detected at dams on the Snake and Columbia Rivers during the spring and summer of 1989, 1990, and 1991.

Methods

Fish Collection and Tagging

From 1988 through 1990, during August and September, we collected and PIT-tagged wild spring and summer chinook salmon parr in 15 streams in Idaho and 4 streams in Oregon. Fish were collected and tagged from various reaches of each stream. Two primary methods were used to collect fish for tagging--electroshocking and a seining technique that we developed specifically for this application. The seining method was used when fish densities were high. Electro-shocking was employed only when necessary, and was particularly useful when fish densities in the streams were low.

For this study, tagging operations were conducted using two portable PIT-tagging stations designed and constructed by the National Marine Fisheries Service (NMFS) specifically for field use (Prentice et al. 1990c). After tagging, fish were allowed to recover in a bucket of fresh water, transferred to a live cage in the stream, and held for a minimum of one-half hour before release. Tagged fish were released in the streams as near as possible to the exact locations from which they were collected. Approximately 8-12% of the tagged fish from most streams were held for 24 hours in live cages in the streams to measure tag loss and delayed mortality.

To provide comparative data on hatchery fish, we PIT-tagged spring chinook salmon parr at Sawtooth Hatchery in Idaho for all three out-migration years, at Lookingglass Creek Hatchery in Oregon for the 1989 out-migration, and at Dworshak Hatchery for the 1990 and 1991 out-migrations. The hatchery fish were tagged in late winter or early spring in each of the three years. In addition, the Idaho Department of Fish and Game PIT-tagged an additional group of spring chinook salmon parr at Sawtooth Hatchery that were released in the fall of 1988, and groups of summer chinook salmon at McCall Fish Hatchery that were released with normal production fish in the South Fork of the Salmon River in 1989 and 1991.

Detections at Dams

During the spring and summer of 1989, 1990, and 1991, surviving chinook salmon PIT tagged the previous summer migrated downstream volitionally through the hydroelectric complex on the Snake and Columbia Rivers. PIT-tag monitoring systems were installed at Lower Granite and Little Goose Dams on the Snake River and McNary Dam on the Columbia River. Smolts were guided by submersible screens from the turbine intakes into the juvenile bypass systems at these dams. They were electronically interrogated for PIT tags after passage from the fish and debris separators into the fish distribution flumes (Prentice et al. 1990a).

Detection totals and percentages were based on first-time detections of PIT tags at the three collector dams. That is, PIT tags detected at Little Goose or McNary Dams that were previously detected at Lower Granite Dam were subtracted from the total detected for Little Goose or McNary Dams. Run-proportion passage at Lower Granite Dam for various combined populations was calculated by totaling the detections of all groups of interest in 3-day intervals and dividing by the total detected during the season for the same groups.

Results and Discussion

Fish Collection and Tagging

A total of 45,158 PIT-tagged wild spring and summer chinook salmon parr were released in Idaho and Oregon streams during the 3 years of study (Table 1). To provide comparative data, a total of 55,348 hatchery chinook salmon smolts were PIT-tagged and released.

Collecting, tagging, and 24-hour delayed mortalities were low for all 3 study years (Table 2). In 1988 and 1989, the chinook salmon parr densities were sufficiently high in most streams to allow collection by seine. The slight increase in collecting mortality in Idaho in 1990 compared with the previous 2 years may have been due to collecting with electro-shockers. Overall tagging mortality declined during the study, presumably because of experience gained in fish handling and tagging. To estimate delayed mortality and tag loss, 4,977 fish were held 24 hours in the streams after tagging. Over the 3 years of study, delayed mortality ranged from 0.0% for fish tagged in Oregon in 1988 to 2.5% for fish tagged in Idaho in 1989. Overall mortality from collection, tagging, and 24-hour delayed mortality was 1.0%.

Detections at Dams

A total of 18,770 PIT tags were detected (first-time detections) at the three collector dams combined during the 3 years of study. Of these, 4,061 originated from wild releases and 14,709 originated from hatchery releases (Table 3).

The detection rates for wild and hatchery releases at the three collector dams varied among the 3 years (Table 3). Detection rates from wild releases increased over the 3 years. In 1991, they were 33.0% higher than in 1990 and 59.2% higher than in 1989 for the three collector dams combined. Conversely, detection rates for hatchery releases declined over the 3 years, with 1991 rates measuring 25.9% lower than in 1990 and 70.8% lower than in 1989.

Out-Migration Timing at Lower Granite Dam

The out-migration timing of wild spring chinook salmon at Lower Granite Dam varied among individual streams and was generally protracted, while timing of hatchery spring chinook salmon was early and compressed each year (Table 4). Few hatchery fish were detected at the dam after 15 May.

In 1991, the overall wild spring chinook salmon out-migration at Lower Granite Dam was characterized by a single large peak around 20 May, during the highest river flow and turbidity of the year. The 50th

TABLE 1.—Summary of the numbers of wild and hatchery spring and summer chinook salmon collected, PIT tagged, and released, with average lengths and weights, 1988-91.

Tagging location	No. collected	No. PIT tagged and released	Average fork length (mm)	Average weight (g)
		1988-89		
IDAHO				
Crooked River	2,479	2,464	69	3.8
Red River	3,602	2,532	75	5.0
East Fork Salmon River	745	742	74	5.6
Upper Salmon River	2,789	2,720	75	5.1
Alturas Lake Creek	415	415	83	7.0
Valley Creek	2,521	2,251	66	3.5
Secesh River	2,349	2,178	69	4.1
Lake Creek	678	664	66	3.6
South Fork Salmon River	2,968	2,184	63	3.4
Totals or averages	**18,546**	**16,150**	**70**	**4.3**
OREGON				
Grande Ronde River	3,044	2,984	68	3.6
Imnaha River	1,339	1,207	70	3.4
Totals or averages	**4,383**	**4,191**	**69**	**3.5**
Lookingglass Creek Hatchery	—	10,012	127	—
Sawtooth Hatchery				
fall release	—	2,054	—	—
spring release	—	10,073	117	—
McCall Hatchery	—	2,411	—	—
Totals or averages	—	**24,550**	**122**	—
		1989-90		
IDAHO				
Sulphur Creek	2,599	2,509	70	3.8
Elk Creek	16	16	73	4.2
Marsh Creek	2,810	2,496	67	3.6
Bear Valley Creek	1,610	1,557	68	4.2
Valley Creek	3,342	2,498	66	3.7
Alturas Lake Creek	1,107	1,036	77	5.7
Big Creek	2,456	2,026	65	3.7
Secesh River	2,542	2,359	66	3.1
Totals or averages	**16,482**	**14,497**	**68**	**3.7**

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TABLE 1.—*continued*

Tagging location	No. collected	No. PIT tagged and released	Average fork length (mm)	Average weight (g)
		1989-90		
OREGON				
Lostine River	84	84	70	4.8
Imnaha River	2,106	1,986	73	3.8
Totals or averages	**2,190**	**2,070**	**73**	**3.8**
Dworshak Hatchery	—	6,629	113	19.5
Sawtooth Hatchery	—	9,943	120	20.3
Totals or averages	—	**16,572**	**117**	**20.0**
		1990-91		
IDAHO				
Bear Valley Creek	358	352	69	4.7
Elk Creek	257	247	76	6.1
Valley Creek	1,089	1,023	68	4.3
Cape Horn Creek	175	164	69	4.6
Marsh Creek	889	861	71	4.9
East Fork Salmon River	573	532	78	6.3
South Fork Salmon River	1,024	986	65	3.4
Big Creek	749	724	67	4.2
Secesh River	1,131	1,016	61	2.9
Totals or averages	**6,245**	**5,905**	**68**	**4.2**
OREGON				
Catherine Creek	1,018	1,012	80	6.3
Lostine River	1,019	1,006	77	4.8
Imnaha River	346	327	69	3.9
Totals or averages	**2,383**	**2,345**	**77**	**4.2**
Dworshak Hatchery	—	6,741	116	19.2
Sawtooth Hatchery	—	7,085	114	18.2
McCall Hatchery	—	400	—	—
Totals or averages	—	**14,226**	**115**	**18.7**

TABLE 2.—Mortality and tag loss for wild spring and summer chinook salmon collected and PIT tagged in Idaho and Oregon, 1988-90.

Tagging location	Mortality (%)			Tag loss (%)	
	Collection	Tagging	24-hour	Overall	24-hour
		1988			
IDAHO					
Crooked River	0.0	0.4	1.4	0.6	0.3
Red River	1.0	1.5	1.0	2.1	0.0
East Fork Salmon River	2.9	0.4	1.0	3.4	0.0
Upper Salmon River	0.0	0.1	0.0	0.1	0.0
Alturas Lake Creek	0.0	0.0	—	0.0	—
Valley Creek	0.1	0.7	2.6	0.9	0.0
Secesh River	0.3	0.8	1.9	1.5	0.2
Lake Creek	0.1	0.2	—	0.3	—
South Fork Salmon River	0.7	1.7	2.6	2.2	0.0
Averages	**0.5**	**0.8**	**1.5**	**1.3**	**0.1**
OREGON					
Grande Ronde River	0.1	0.3	0.0	0.4	0.4
Imnaha River	—	0.7		0.7	—
Averages	**0.1**	**0.5**	**0.0**	**0.5**	**0.4**
		1989			
IDAHO					
Sulphur Creek	0.2	0.3	0.9	0.6	0.0
Elk Creek	0.0	0.0	—	0.0	—
Marsh Creek	0.1	0.2	5.6	0.8	0.0
Bear Valley Creek	0.1	0.1	0.0	0.2	0.0
Valley Creek	0.1	0.4	2.4	0.6	0.0
Alturas Lake Creek	0.3	0.8	—	1.0	—
Big Creek	0.4	0.3	0.9	0.7	0.5
Secesh River	0.0	0.3	5.1	0.6	0.0
Averages	**0.1**	**0.3**	**2.4**	**0.6**	**0.1**
OREGON					
Lostine River	0.0	0.0	—	0.0	—
Imnaha River	0.0	1.1	—	1.1	—
Averages	**0.0**	**1.1**	—	**1.0**	—

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TABLE 2.—*continued*

Tagging location	Mortality (%)			Tag loss (%)	
	Collection	Tagging	24-hour	Overall	24-hour
		1990			
IDAHO					
Bear Valley Creek	1.1	0.0	0.0	1.1	0.0
Elk Creek	1.2	0.0	—	1.2	—
Valley Creek	1.1	0.7	0.0	1.7	0.0
Cape Horn Creek	3.4	0.0	0.0	3.4	0.0
Marsh Creek	1.2	0.0	0.0	1.2	0.0
East Fork Salmon River	6.3	0.0	0.6	6.5	0.0
South Fork Salmon River	1.0	0.4	0.0	1.4	0.0
Big Creek	1.0	0.3	0.0	1.2	0.0
Secesh River	0.4	0.1	1.0	0.6	0.0
Averages	**1.5**	**0.2**	**0.2**	**1.8**	**0.0**
OREGON					
Catherine Creek	0.5	0.0	0.6	0.6	0.0
Lostine River	0.1	0.8	1.1	1.2	0.0
Imnaha River	—	2.1	—	2.0	—
Averages	**0.3**	**0.6**	**0.9**	**1.0**	**0.0**

TABLE 3.—Number and percent of PIT-tagged spring and summer chinook salmon smolts detected at Lower Granite, Little Goose, and McNary Dams, 1989-91.

	Detections					
	Lower Granite Dam		Little Goose Dam		McNary Dam	
Tagging location	Number	Percent	Number	Percent	Number	Percent
			1989			
WILD STREAMS						
Crooked River	44	1.8	16	0.6	9	0.4
Red River	21	0.8	15	0.6	3	0.1
East Fork Salmon River	57	7.7	26	3.5	15	2.0
Upper Salmon River	69	2.5	39	1.4	23	0.8
Alturas Lake Creek	20	4.8	10	2.4	6	1.4
Valley Creek	65	2.9	41	1.8	14	0.6
Secesh River	191	8.8	97	4.5	31	1.4
Lake Creek	51	7.7	24	3.6	6	0.9
South Fork Salmon River	85	3.9	37	1.7	13	0.6
Upper Grande Ronde River	242	8.1	100	3.4	45	1.5
Imnaha River	73	6.0	45	3.7	16	1.3
Totals or averages	**918**	**4.5**	**450**	**2.2**	**181**	**0.9**
HATCHERIES						
Lookingglass Creek Hatchery	1,917	19.1	2,188	21.9	991	9.9
Sawtooth Hatchery						
fall release	64	3.1	31	1.5	10	0.5
spring release	1,058	10.5	580	5.8	228	2.3
McCall Hatchery	529	21.9	244	10.1	93	3.9
Totals or averages	**3,568**	**14.5**	**3,043**	**12.4**	**1,322**	**5.4**
			1990			
WILD STREAMS						
Sulphur Creek	166	6.6	60	2.4	24	1.0
Elk Creek	1	6.2	1	6.2	0	0.0
Marsh Creek	178	7.1	60	2.4	21	0.8
Bear Valley Creek	91	5.8	29	1.9	19	1.2
Valley Creek	76	3.0	42	1.7	27	1.1
Alturas Lake Creek	4	0.4	1	0.1	0	0.0
Big Creek	145	7.2	60	3.0	19	0.9
Secesh River	155	6.6	59	2.5	27	1.1
Lostine River	8	9.5	3	3.6	1	1.2
Imnaha River	160	8.1	49	2.5	31	1.6
Totals or averages	**984**	**5.9**	**364**	**2.2**	**169**	**1.0**

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TABLE 3.—*continued*

	Detections					
	Lower Granite Dam		Little Goose Dam		McNary Dam	
Tagging location	Number	Percent	Number	Percent	Number	Percent
HATCHERIES						
Dworshak Hatch.	1,941	29.3	666	10.0	379	5.7
Sawtooth Hatch.	793	8.0	287	2.9	78	0.8
Totals or averages	**2,734**	**16.5**	**953**	**5.8**	**457**	**2.8**
			1991			
WILD STREAMS						
Bear Valley Creek	44	12.5	22	6.2	2	0.6
Elk Creek	32	13.0	14	5.7	2	0.8
Valley Creek	41	4.0	18	1.8	8	0.8
Cape Horn Creek	25	15.2	8	4.9	1	0.6
Marsh Creek	59	6.9	27	3.1	7	0.8
East Fork Salmon River	18	3.4	14	2.6	6	1.1
South Fork Salmon River	98	9.9	37	3.8	7	0.7
Big Creek	67	9.3	26	3.6	2	0.3
Secesh River	71	7.0	21	2.1	5	0.5
Lostine River	90	8.9	47	4.7	19	1.9
Catherine Creek	77	7.6	41	4.1	7	0.7
Imnaha River	18	5.5	9	2.8	5	1.5
Totals or averages	**640**	**7.8**	**284**	**3.4**	**71**	**0.9**
HATCHERIES						
Dworshak Hatchery	1,632	24.2	333	4.9	89	1.3
Sawtooth Hatchery	307	4.3	90	1.3	43	0.6
McCall Hatchery	97	24.2	31	7.8	10	2.5
Totals or averages	**2,036**	**14.3**	**454**	**3.2**	**142**	**1.0**
Grand Totals Recovered	**18,770**					
	4,061 Wild fish					
	14,709 Hatchery fish					

TABLE 4.—The out-migration timing of spring and summer chinook salmon smolts at Lower Granite Dam for individual streams and hatcheries, 1989-91.

Tagging location	Passage dates at Lower Granite Dam			
	50%	Peak(s)	90%	Range
		1989		
WILD SPRING CHINOOK SALMON				
Crooked River	9 Jun	11, 30 Jun	30 Jun	11 Apr-15 Jul
Red River	26 May	3 May	20 Jun	9 Apr-30 Jun
East Fork Salmon River	3 May	23, 24 Apr	18 May	7 Apr-8 Jun
Upper Salmon River	9 May	26 Apr, 4, 10, 13 May	4 Jun	9 Apr-17 Jun
Alturas Lake Creek	16 May	10, 16 May	6 Jun	24 Apr-8 Jun
Valley Creek	14 May	24 Apr, 3 May, 12 Jun	12 Jun	9 Apr-17 Jun
Upper Grande Ronde River	6 Jun	9 Jun	19 Jun	27 Apr-22 Jul
HATCHERY SPRING CHINOOK SALMON				
Lookingglass Hatchery	21 Apr	22 Apr	29 Apr	8 Apr-3 Jun
Sawtooth Hatchery				
fall release	25 Apr	22 Apr	11 May	26 Mar-8 Jun
spring release	25 Apr	22 Apr	11 May	6 Apr-17 Jun
WILD SUMMER CHINOOK SALMON				
Secesh River	27 Apr	21, 25 Apr	9 Jun	9 Apr-19 Jul
Lake Creek	2 May	1 May	16 Jun	12 Apr-1 Jul
South Fork Salmon River	13 May	13 May, 12 Jun	14 Jun	16 Apr-20 Jun
Imnaha River	30 Apr	4, 17 Apr, 4 May	11 May	4 Apr-5 Jun
HATCHERY SUMMER CHINOOK SALMON				
McCall Hatchery	10 May	10 May	1 Jun	18 Apr-20 Jun
		1990		
WILD SPRING CHINOOK SALMON				
Sulphur Creek	30 Apr	23 Apr	31 May	11 Apr-27 Jun
Marsh Creek	29 Apr	23 Apr	31 May	9 Apr-1 Jul
Bear Valley/Elk Creek	2 May	20, 22, 26 Apr, 31 May	31 May	11 Apr-18 Jul
Valley Creek	8 May	19 Apr, 31 May	5 Jun	12 Apr-29 Jun
Alturas Lake Creek	*a*			20 Apr-30 May
Big Creek	30 May	31 May	22 Jun	17 Apr-18 Jul
Lostine River	*a*			30 Apr-31 May

continued on next page

TABLE 4.—*continued*

Tagging location	Passage dates at Lower Granite Dam			
	50%	Peak(s)	90%	Range
HATCHERY SPRING CHINOOK SALMON				
Dworshak Hatchery	24 Apr	20 Apr	11 May	9 Apr-2 Jun
Sawtooth Hatchery	22 Apr	22 Apr	28 Apr	7 Apr-31 May
WILD SUMMER CHINOOK SALMON				
Secesh River	22 Apr	14, 19, 20 Apr	7 Jun	10 Apr-13 Jul
Imnaha River	18 Apr	12 Apr	9 May	5 Apr-27 May
		1991		
WILD SPRING CHINOOK SALMON				
Bear Valley Creek	20 May	21 May	12 Jun	18 Apr-23 Jun
Elk Creek	20 May	21 May	16 Jun	25 Apr-24 Jun
Valley Creek	20 May	20 May	20 Jun	21 Apr-13 Jul
Cape Horn Creek	16 May	17 May	28 May	19 Apr-6 Jun
Marsh Creek	20 May	20 May	9 Jun	17 Apr-18 Jun
East Fork Salmon River	9 May	23 Apr, 11 May	26 May	16 Apr-20 Jun
Big Creek	10 Jun	14 Jun	26 Jun	26 Apr-1 Jul
Lostine River	14 May	13 May	26 May	20 Apr-9 Jul
Catherine Creek	14 May	12, 20 May	8 Jun	17 Apr-23 Jun
HATCHERY SPRING CHINOOK SALMON				
Dworshak Hatchery	25 Apr	24 Apr	9 May	9 Apr-23 May
Sawtooth Hatchery	3 May	24 Apr	17 May	14 Apr-12 Jun
WILD SUMMER CHINOOK SALMON				
South Fork Salmon River	16 May	20 Apr, 22 May	10 Jun	17 Apr-13 Jul
Secesh River	27 Apr	24 Apr	14 Jun	13 Apr-20 Jul
Imnaha River	1 May	8 May	13 May	14 Apr-15 May
HATCHERY SUMMER CHINOOK SALMON				
McCall Hatchery	14 May	12 May	4 Jun	26 Apr-22 Jun

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[a] Insufficient recoveries

percentile of these fish passed the dam by 19 May and the 90th percentile passed by 15 June. Although the peak out-migration periods occurred at different times in 1989, the 50th and 90th percentile passage times were similar to those in 1991. In 1990, the 50th and 90th percentile passage dates were earlier, with 50% passing by 7 May and 90% passing by 5 June.

The overall hatchery spring chinook salmon out-migration peaked during the same 3-day period (22-24 April) in all 3 years, and the 50th and 90th percentile passage dates were generally from 21 through 26 April, and from 4 through 10 May, respectively.

Out-migration timing of wild summer chinook salmon also varied among years. These fish were abundant at the dam earlier than both their hatchery counterparts and wild spring chinook salmon (Table 4). During all 3 years, peak out-migration periods occurred most frequently in April for wild summer chinook salmon. In both 1989 and 1991, the 50th percentile of these fish passed the dam by the first 2 weeks of May and the 90th percentile passed by the second week of June. In 1990, wild summer chinook salmon were the earliest arriving stock at the dam, with 50% passing by 20 April and 90% passing by 7 June, although it should be noted that the majority of the fish from the two wild summer chinook salmon streams combined had passed by mid-May.

Hatchery summer chinook salmon from McCall Hatchery released in the South Fork of the Salmon River peaked in mid-May in both 1989 and 1991 (Table 4). The 50th and 90th percentile passage for these fish occurred by mid-May and early June, in both years.

In conclusion, the occurrence of wild stocks of spring and summer chinook salmon smolts at Lower Granite Dam differed in all 3 years. Moreover, the out-migration timing of individual wild spring chinook salmon streams was more variable within and among years than individual wild summer chinook salmon streams. In all 3 years, the wild spring and summer chinook salmon out-migrations were protracted, encompassing nearly the entire spring and early summer migration periods. Wild summer chinook salmon were in greater abundance early during all three migration seasons, while wild spring chinook salmon were abundant late during all three migration seasons. We observed opposite out-migration timing trends for their hatchery counterparts. Hatchery spring chinook salmon displayed early compressed timing, while hatchery summer chinook salmon displayed late compressed timing.

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Emigration Characteristics of Spring Chinook from Crooked River and Upper Salmon River, Idaho

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Introduction

Data for this paper were collected as part of an ongoing research project funded by the Bonneville Power Administration. Our objectives are to determine the mathematical relationship between adult spawning escapement and smolt production for both spring chinook salmon *Oncorhynchus tshawytscha* and summer steelhead trout *O. mykiss*, and to develop mitigation accounting techniques that are based on increases in smolt production. Field work began in 1987 on two study areas (Crooked River and upper Salmon River, Idaho) to meet these objectives.

Crooked River originates at an elevation of 2,070 m in the Clearwater Mountains within the Nez Perce National Forest and enters the South Fork Clearwater River at river kilometer 94 at an elevation of 1,140 m (Figure 1). The Crooked River study area (CR) consists of the entire drainage upstream of the adult trapping weir located 0.2 km above the mouth. Flows on Crooked River range from 0.2 to 14.3 m^3/s, and conductivity ranges from 35 to 50 μmhos/cm (Mann and Von Lindern 1987).

The Salmon River originates in the Sawtooth, Smokey, and White Cloud mountains in south-central Idaho (Figure 2). The upper Salmon River study area (USR) consists of the entire drainage upstream of the adult trapping weir for Sawtooth Fish Hatchery. Elevations range above 1,980 m. Water flows at the Sawtooth Fish Hatchery weir range from 1.7 to 23.3 m^3/s, and conductivity ranges from 37 to 218 μmhos/cm (Emmett 1975).

Methods

Our methods for this research project include using weirs to enumerate adults, conducting ground and aerial redd counts, snorkeling to estimate parr populations, Passive Integrated Transponder (PIT) tagging of parr to determine parr-to-smolt survival, trapping fall and spring emigrants with scoop traps, and outplanting adults to determine habitat carrying capacity. Methods focused on in this paper are snorkeling, PIT tagging, and emigrant trapping.

We estimated parr abundance by species and age class by snorkeling through established transects (Petrosky and Holubetz 1985). We conducted surveys on 31 to 34 transects on Crooked River and 81 to 89 transects on the upper Salmon River during July of each year from 1987 to 1991. We estimated total abundance of steelhead and chinook parr by stratified sampling (Schaeffer et al. 1979).

We PIT tagged chinook and steelhead parr from representative rearing areas in each study area during August of each year. We collected parr for PIT tagging with seines or a Smith-Root model 12 electrofisher, depending on which method was most suitable for each particular site and species. Seines were used to sample pools, primarily for chinook, and the electrofisher was used to sample riffles, primarily for steelhead. Our goal was to PIT tag at least 500 chinook and 300 steelhead parr from each representative rearing area. Our tagging procedures included anesthetizing fish with MS-222 and injecting PIT tags into the body cavity using a 12-gauge hypodermic needle and modified syringe (Kiefer and Forster 1991).

We monitored fall and spring emigration of juvenile anadromous fish in both study areas with floating scoop traps equipped with a 1.0-m-wide inclined traveling screen. During the fall emigration, these traps were operated continuously from mid-August through early November. For the spring emigration, we operated the traps continuously from early March through early June. To determine emigration timing and survival

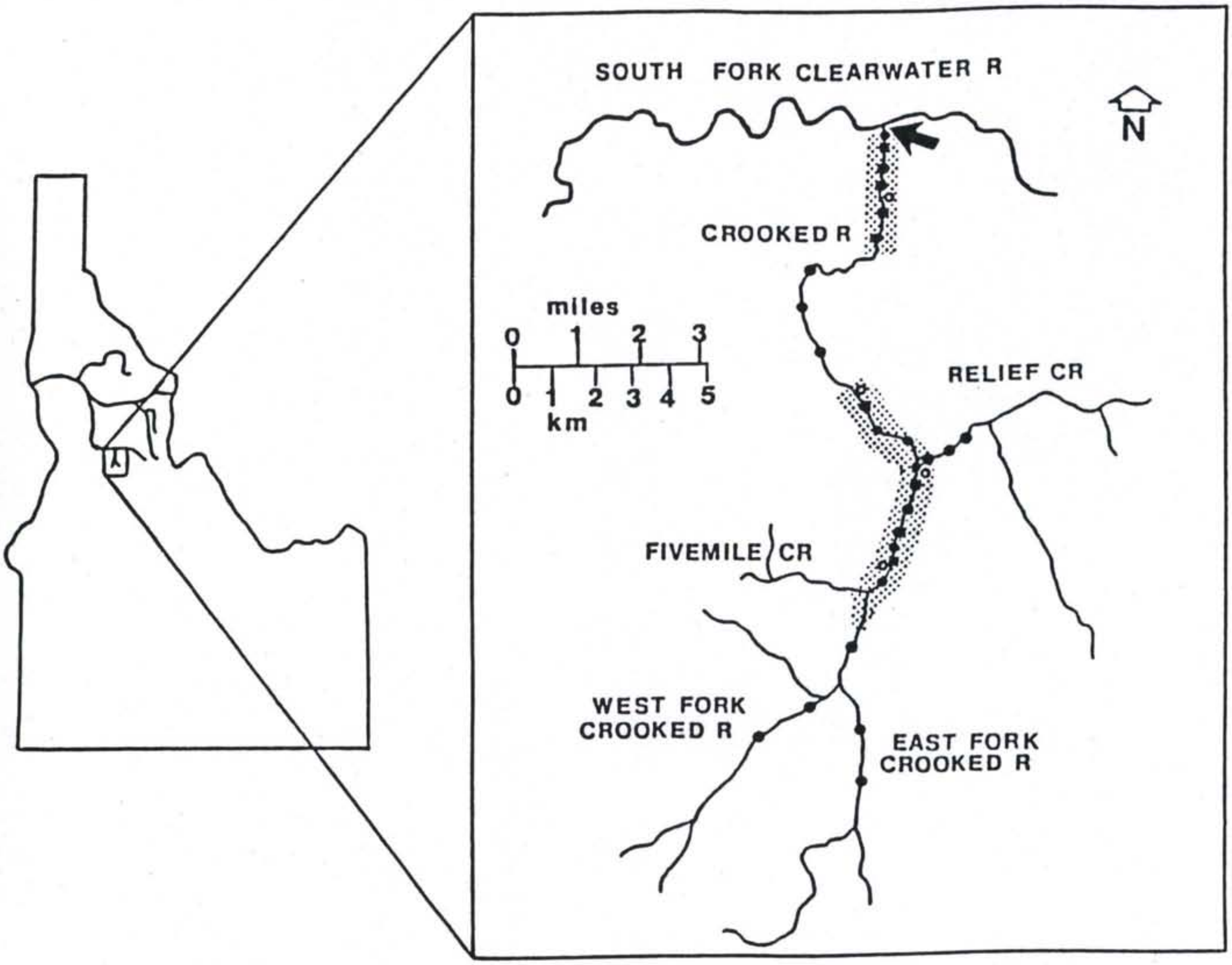

Figure 1. Locations of Crooked River, meadows degraded by dredging (shaded), and river (●) and pond (o) study section locations. Arrow indicates location of trapping facility.

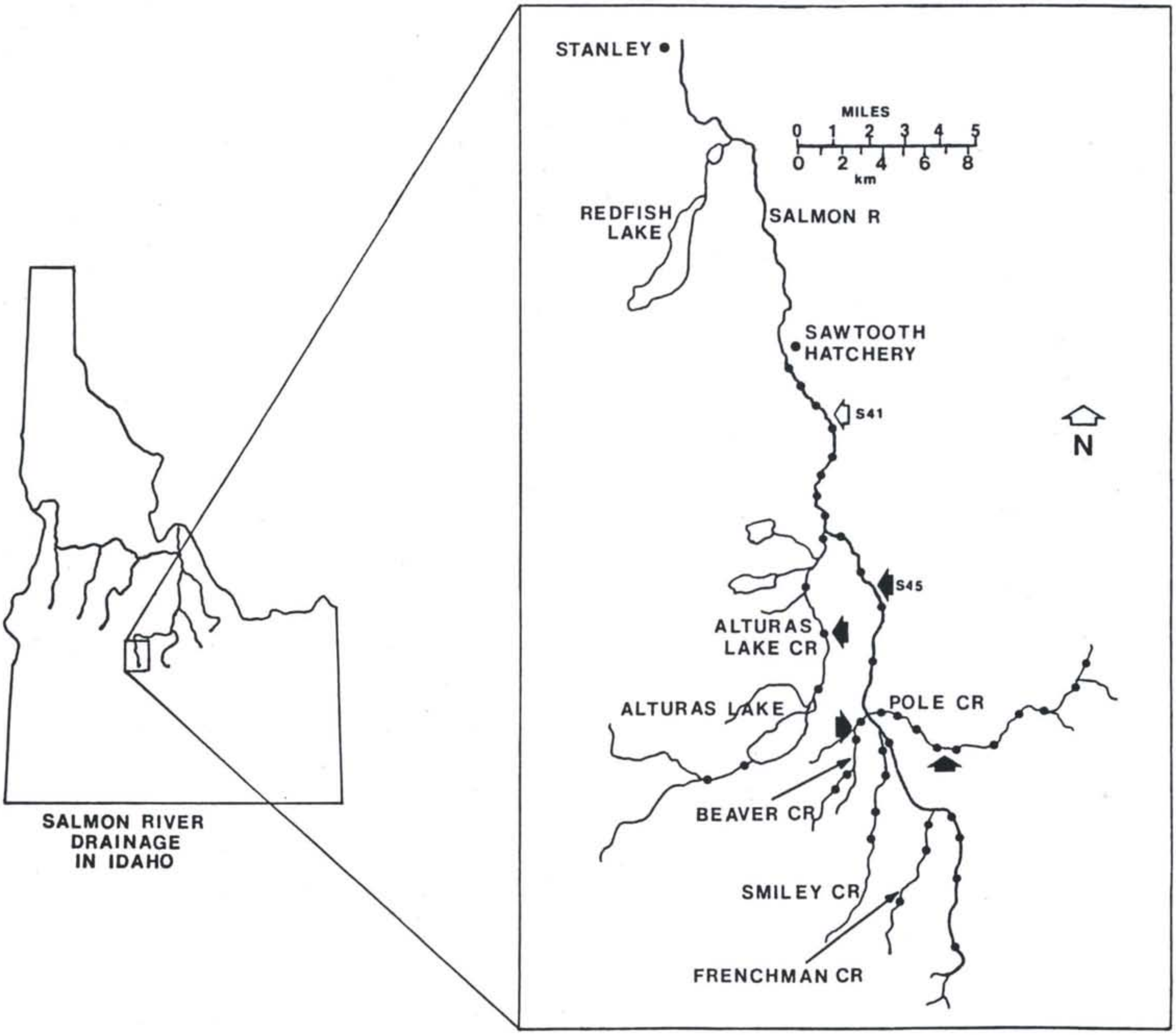

Figure 2. Location of the upper Salmon River study area and study sections (●). Solid arrow indicates major irrigation diversions.

characteristics, we PIT tagged and released fish captured by these traps daily. PIT tagged fish were released at least 200 m upstream of the trap so that we could collect recaptures and estimate trap efficiency. We estimated trap efficiency for several ranges of flow in each trapping season. We estimated total emigration by adding all daily run estimates, which we calculated by dividing each day's total catch by the estimated trap efficiency for the range of flows that day was in. We released all recaptured fish just downstream of the trap.

Results and Discussion

Emigration Characteristics

We found that a greater proportion of the chinook population emigrated in the fall from the higher-elevation USR than from CR, and that the peak of fall emigration from USR occurred earlier than from CR (Figure 3). An average of 62% of the July parr population in the USR emigrated in the fall. For CR, the average fall parr emigration was 24% of the population. These results are consistent with the theory that the juveniles emigrate in the fall to avoid harsh winter conditions such as scour ice in headwater rearing areas. CR, because of its lower elevation, does not have the problem with scour ice that the USR does. Data collected by Bjornn (1978) from the Lemhi River and Marsh Creek (Salmon River drainage) is also consistent with this theory. Thus, many parr overwinter in larger and lower-elevation mainstem streams. Even with a tenfold difference in chinook population numbers observed during different years of this study, the proportion of the chinook population emigrating in the fall from both study areas remained fairly constant. I believe this indicates that lack of suitable overwintering habitat is not causing the juveniles to emigrate.

Of the parameters that we analyzed (water temperature, flow, barometric pressure, and moon phase) significant drops in water temperature, especially those below 4.0°C, and new moon phases appear to be the major stimuli for emigration in the fall (Figure 4). The moon phase data and our observation that almost all emigration occurs at night supports the theory that the juveniles move during periods of low light to avoid predation.

During the spring, both CR and USR had very similar emigration curves. Chinook smolts from the USR appear to emigrate in the spring slightly earlier than did smolts from CR (Figure 5). Because CR is lower in elevation, warms up earlier, and has an earlier peak in discharge, we had originally hypothesized that the smolts from CR would have emigrated earlier than those from USR. The proportion of the previous July chinook parr populations that emigrated in the spring was 15% for USR and 24% for CR. From the difference between the proportion of the July parr population that emigrates in the fall and that which emigrates in the spring, we estimated that minimum overwinter survival for CR and USR averaged 32% and 39%, respectively. These overwinter survival estimates are only minimums because they do not include July-September mortality, and any use of these estimates should also state this limitation. When we analyzed various parameters (water temperature, flow, barometric pressure, and moon phase) for correlation with spring smolt emigration, significant increases in flow appeared to stimulate emigration. None of the other parameters appeared to have a strong correlation with spring emigration.

Travel Time

The detection of PIT tagged juvenile chinook at the lower Snake and Columbia River hydroelectric dams with smolt collection facilities allows us to determine migration characteristics and relative survival. Average travel time for spring emigrants from CR to Lower Granite Reservoir dam (LGR dam) was very similar during the past three low-flow years (Figure 6). One trend noted in these graphs is that as the spring smolt emigration season progresses, the travel time to LGR dam decreases. Even though there is considerable variation in detection rates during different periods of a given spring emigration season, the overall trend is that as the season progresses and travel time decreases, the detection rate increases (Figure 7). The graphs of travel time and detection rate for spring smolts tagged in USR are very similar to those tagged in CR. An interesting finding was that for any given period in the spring emigration, the travel time from CR and

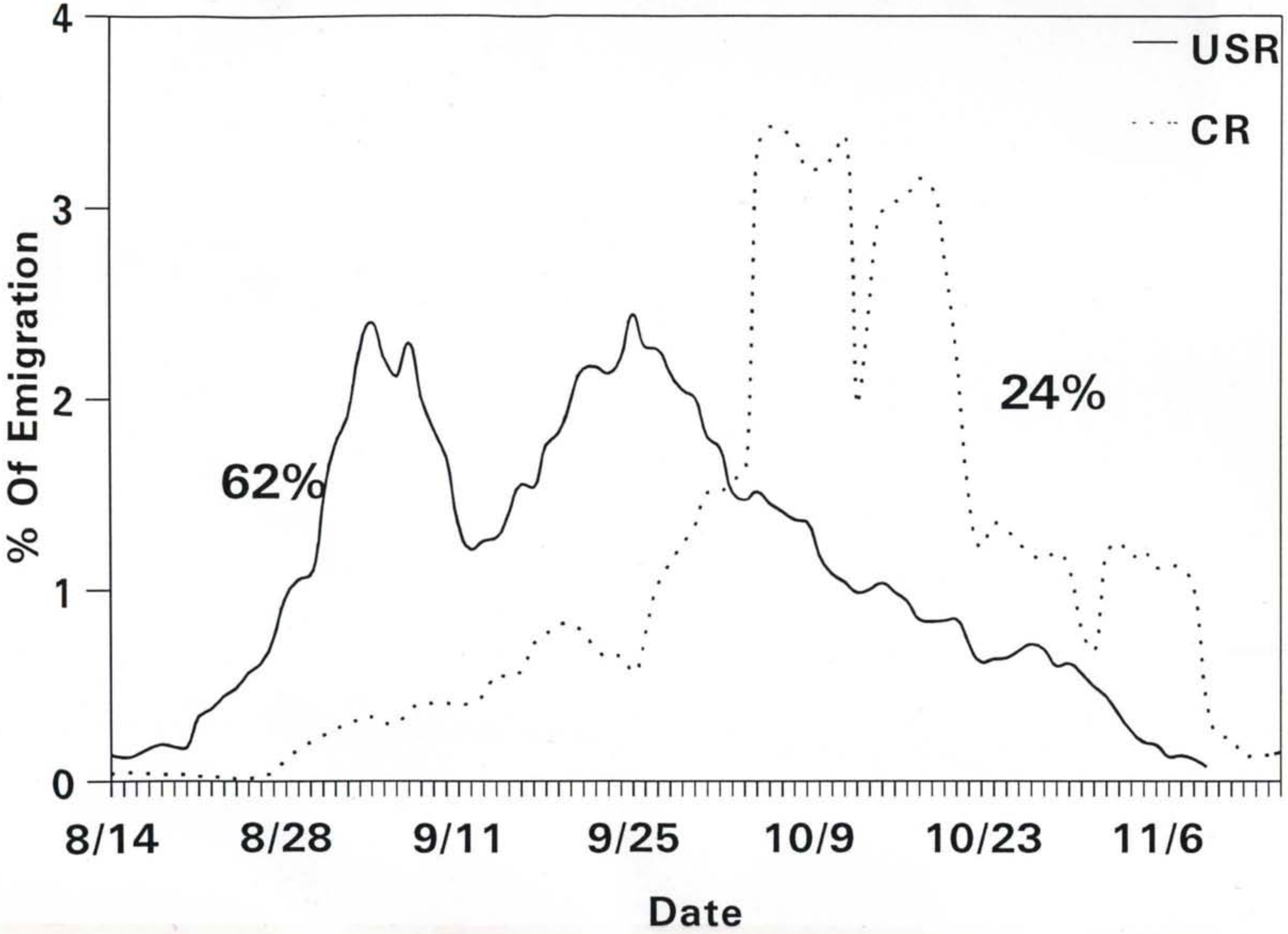

Figure 3. Chinook fall emigration timing from Crooked River and upper Salmon River (7 day moving averages of 1988-1991 data), numbers represent % of summer population emigrating.

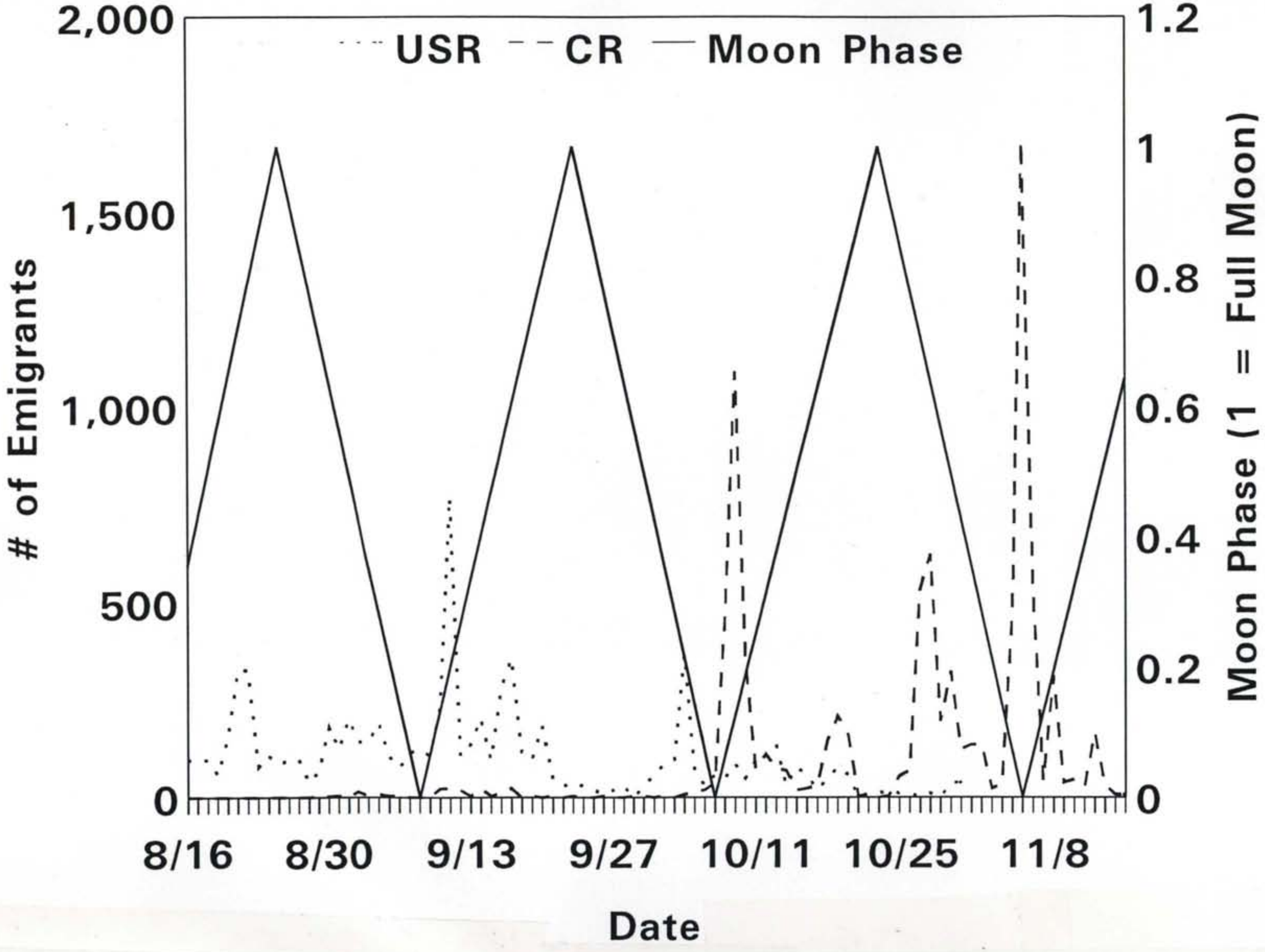

Figure 4. Fall 1991 Crooked River and upper Salmon River chinook emigration timing and moon phase.

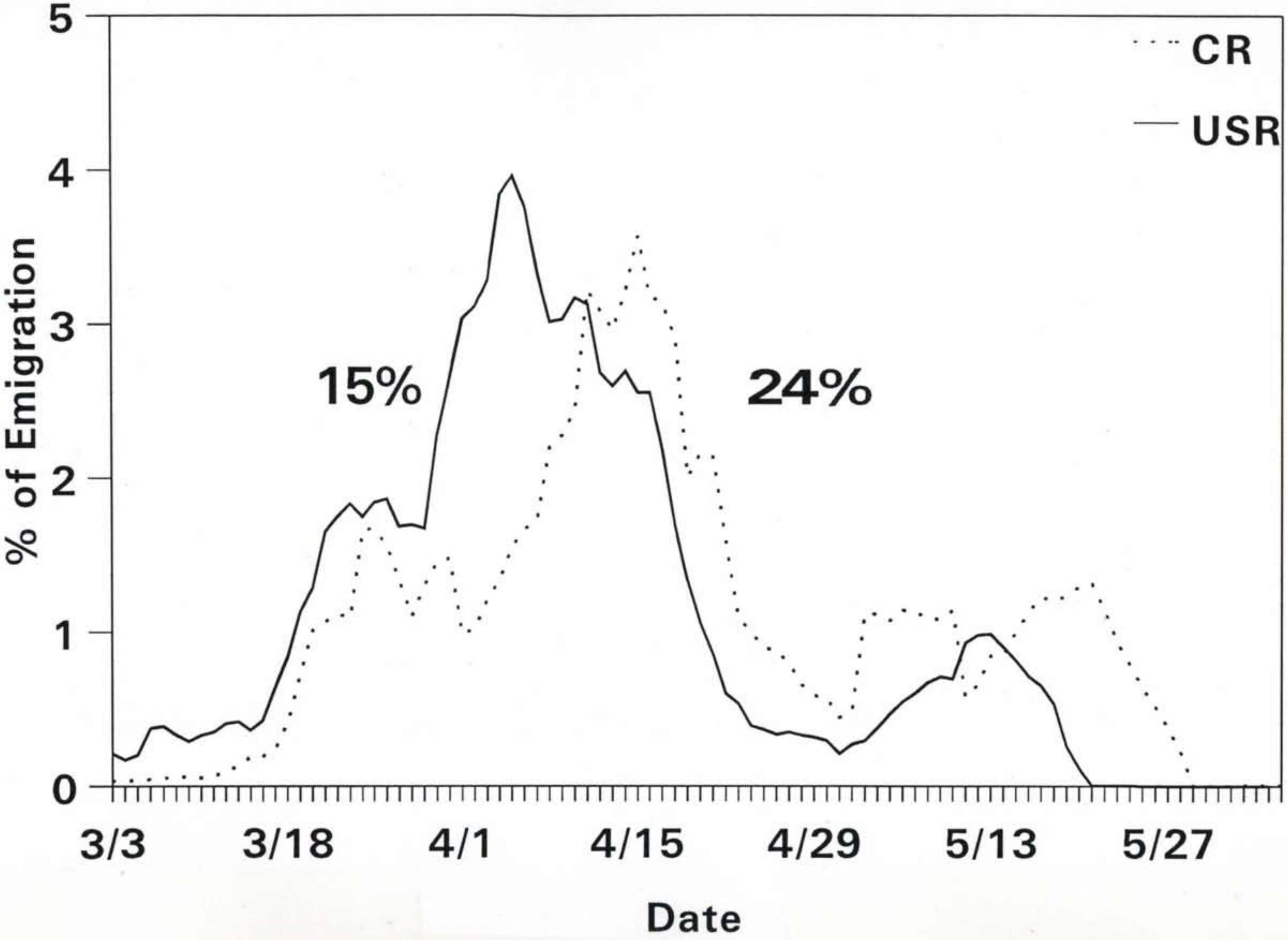

Figure 5. Chinook spring emigration timing from Crooked River and upper Salmon River (7 day moving averages of 1988-1991 data), numbers represent % of summer population emigrating.

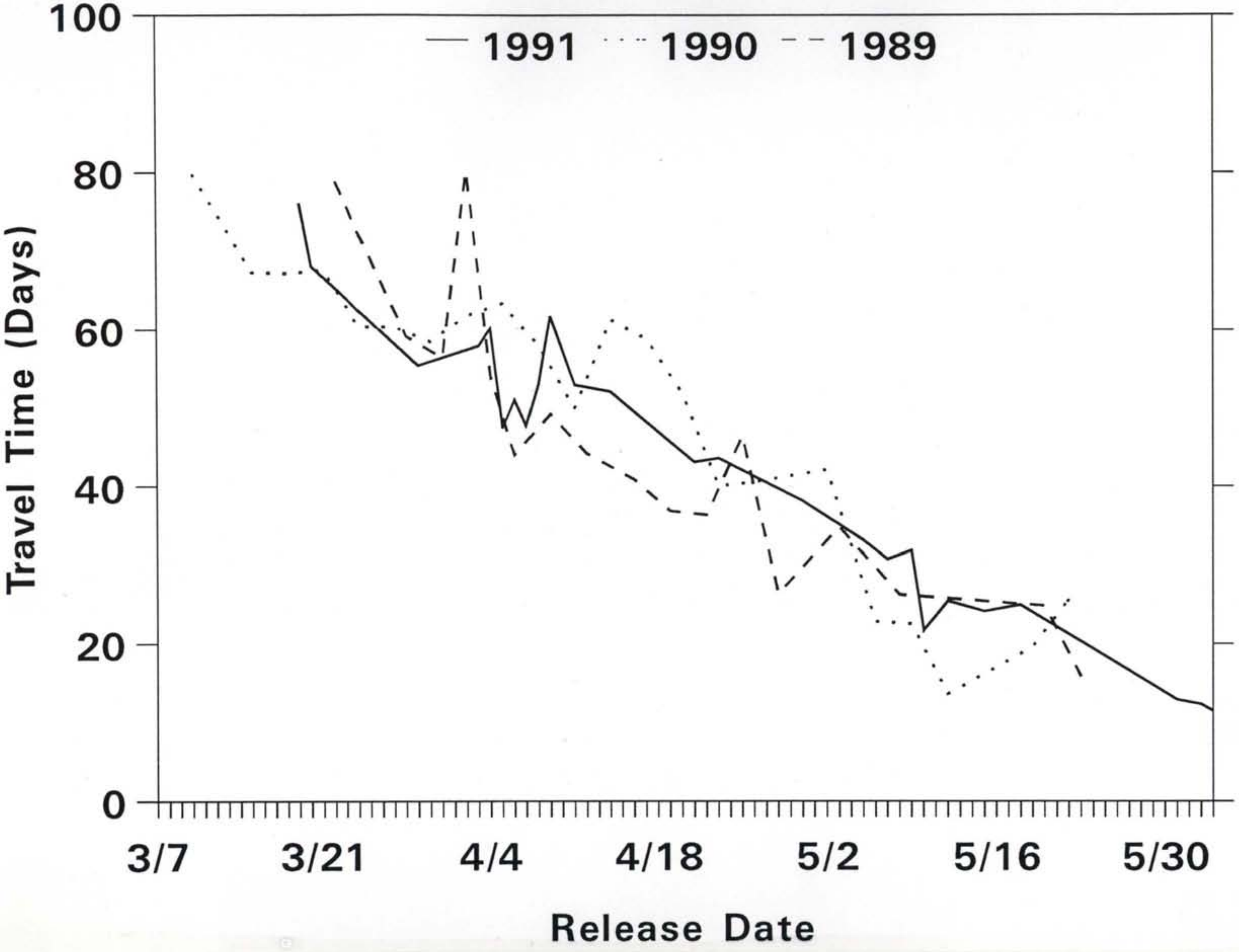

Figure 6. Crooked River chinook smolt travel time to Lower Granite Dam.

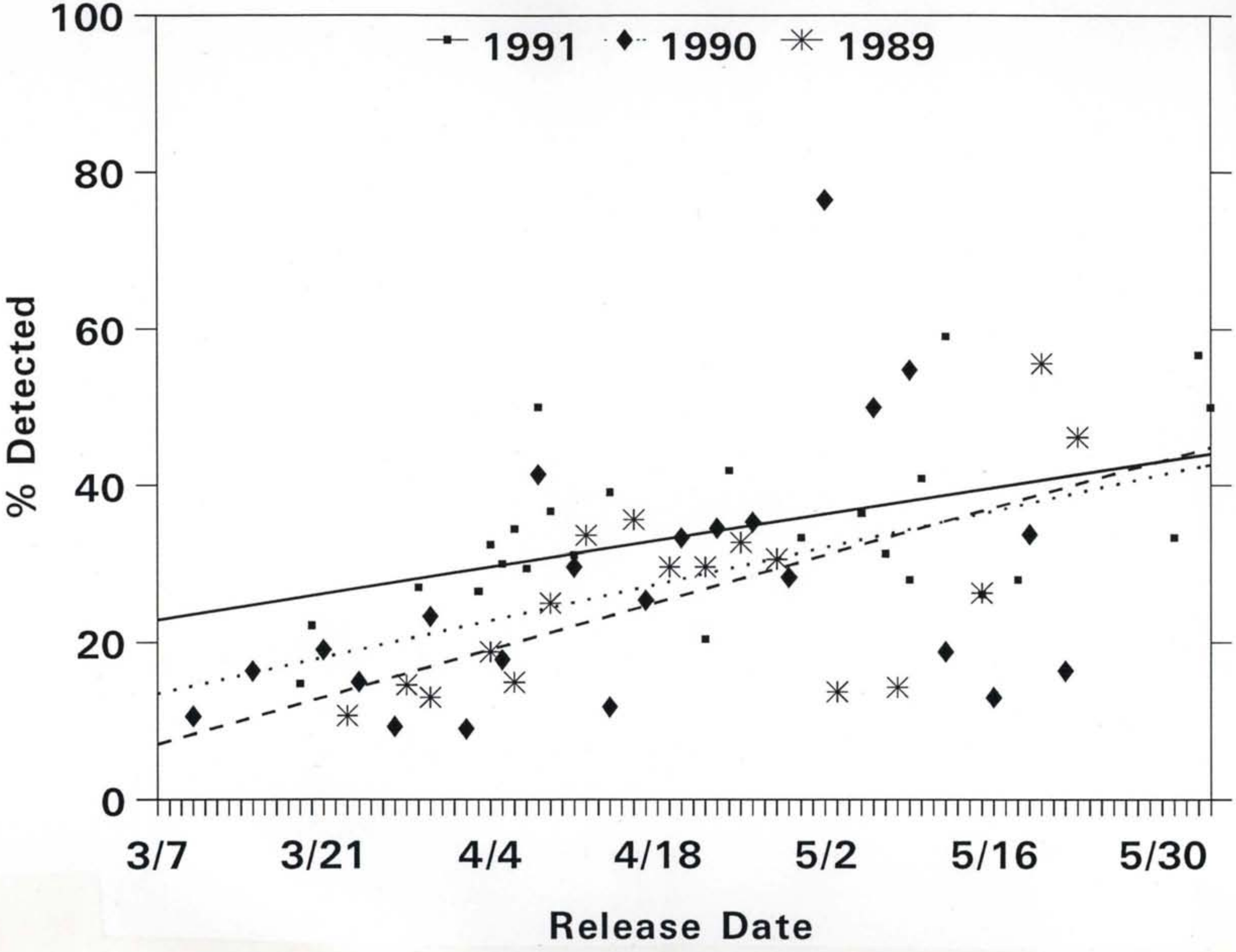

Figure 7. Crooked River chinook smolt PIT tag detection rates and trend lines.

dam significantly later than the entire chinook run, which is comprised primarily of hatchery reared fish (Figure 8). Data collected by Mathews et al. (1992) shows that the arrival timing of the natural spring chinook in our study is fairly representative of the arrival timing at LGR dam of naturally produced spring chinook stocks from the upper Snake River basin, and that the majority of the early arriving spring chinook smolts are hatchery fish. It is important to note that although USR is three times further from LGR dam than CR, the arrival timing at LGR dam is earlier for the chinook smolts from USR. This difference in arrival time at LGR dam in our study, and similar results observed by Mathews et al. (1992), show that individual naturally produced spring chinook stocks have unique migration timings to LGR dam. We hypothesize that these different arrival timings at LGR dam are probably genetically controlled, indicating differences between these stocks.

Another important observation from our data and that collected by Mathews et al. (1992) is that all major peaks in arrival timing at LGR dam for both hatchery and naturally produced spring chinook corresponded with peaks in flows at LGR dam (Figure 9). We recommend that efforts to improve migration rates and survival of naturally produced spring chinook smolts through the lower Snake River hydroelectric system occur during the entire smolt migration season in order to protect all naturally produced stocks.

When separated by season of tagging, the PIT tag detection data from our study provides additional information on migration characteristics. First, the fall emigrants generally arrive at LGR dam earlier than the spring emigrants (Figures 10 and 11), although the difference is not as pronounced for USR fish. And second, these two figures illustrate the difference between these two study areas in the proportion of the population that emigrates in the fall, with the USR proportion being much greater.

PIT Tag Discrepancy

We have observed evidence in our PIT tag data indicating there is higher mortality in our summer and fall PIT tagged parr than in corresponding unmarked parr. The first indication of this potential problem came from our estimates of smolt production. The estimates of smolt production from our July snorkel count population estimates and subsequent detection rates for August PIT tagged parr were consistently lower than the combined fall and spring emigration smolt production estimates using subsequent emigrant PIT tag detections. The smolt production estimates from the summer data should have actually been slightly higher since they do not include July to August mortality.

The next piece of information indicating a long-term PIT tag mortality in the field came from our analysis of the survival rate estimates of fall and spring emigrants from the USR. Our data indicates that it is a survival disadvantage for a chinook juvenile to emigrate in the fall from USR or CR. For USR this is contrary to what would be expected from a population in which 64% of the parr emigrate in the fall. I do not believe that 64% of a population would emigrate in the fall irrespective of population levels if it was a survival disadvantage to do so.

The third and strongest evidence of delayed mortality of summer PIT tagged chinook parr comes from Peterson Mark Recapture (M/R) analysis of recaptures of August PIT tagged parr during our emigration trapping operations. The M/R chinook parr population estimates averaged 3.6 times greater than our snorkel count estimates (Figure 12). Only twice did the 95% confidence intervals slightly overlap for these two methods of estimating the summer parr populations (Table 1). If we assume that (1) our snorkel count method is not grossly underestimating the population, (2) we PIT tag representative groups of parr, and (3) our emigrant trap catches are at least representative of the emigrations, then the only possibility for this discrepancy in population estimates is that tag loss, failure, and/or delayed mortality of PIT tagged summer parr is significant. This possible problem with summer PIT tagged parr in the wild is contrary to what has been observed in hatchery studies (Prentice et al. 1986; Kiefer and Forster 1991; and Mathews et al. 1992). The reasons for this difference are not known at this time, but we strongly urge caution in estimating survival rates based on summer PIT tagging until the question of delayed mortality can be answered.

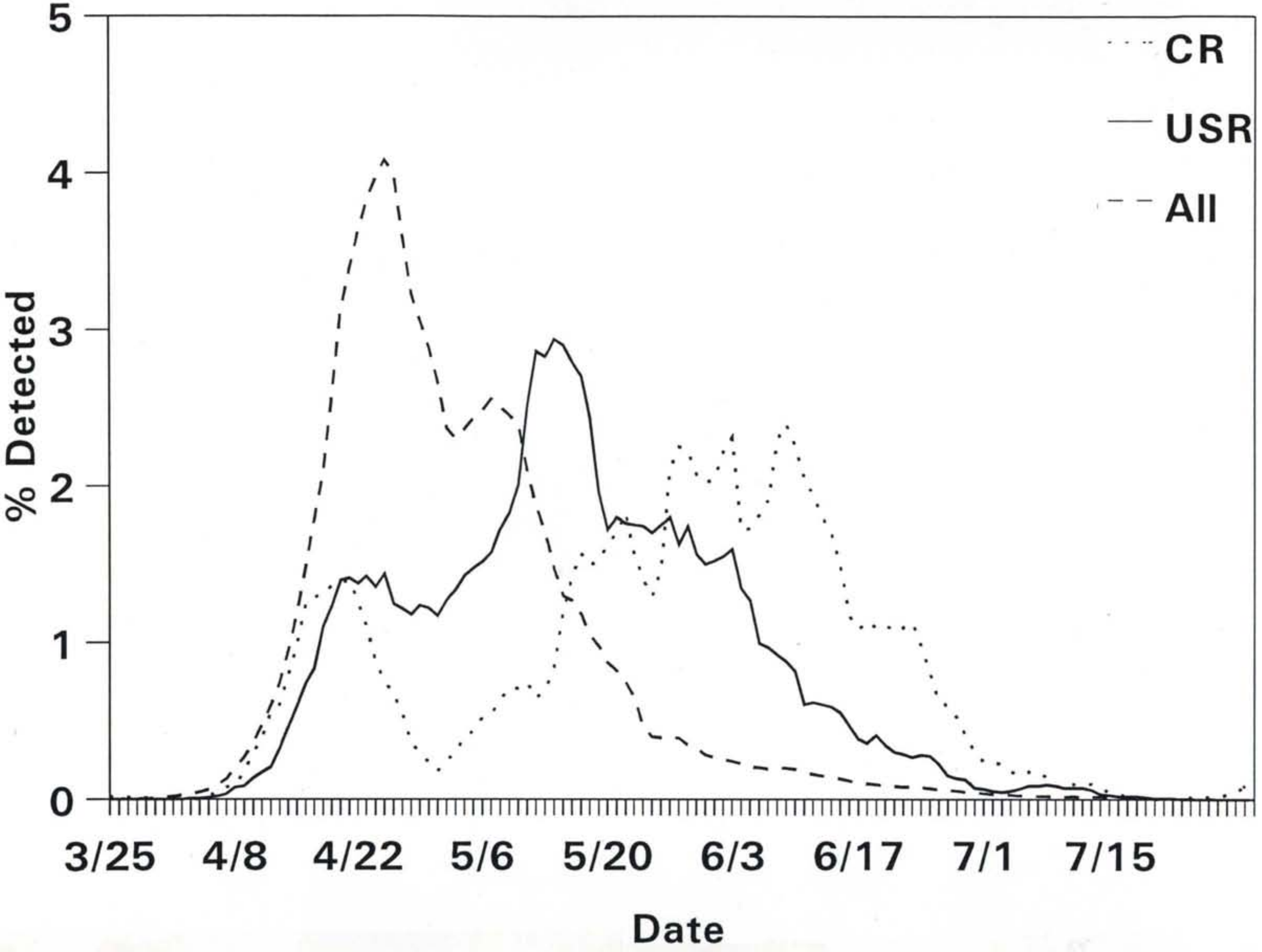

Figure 8. Chinook arrival timing at Lower Granite Dam; Crooked River, upper Salmon River, and all chinook (7 day moving averages of 1988-1991 data).

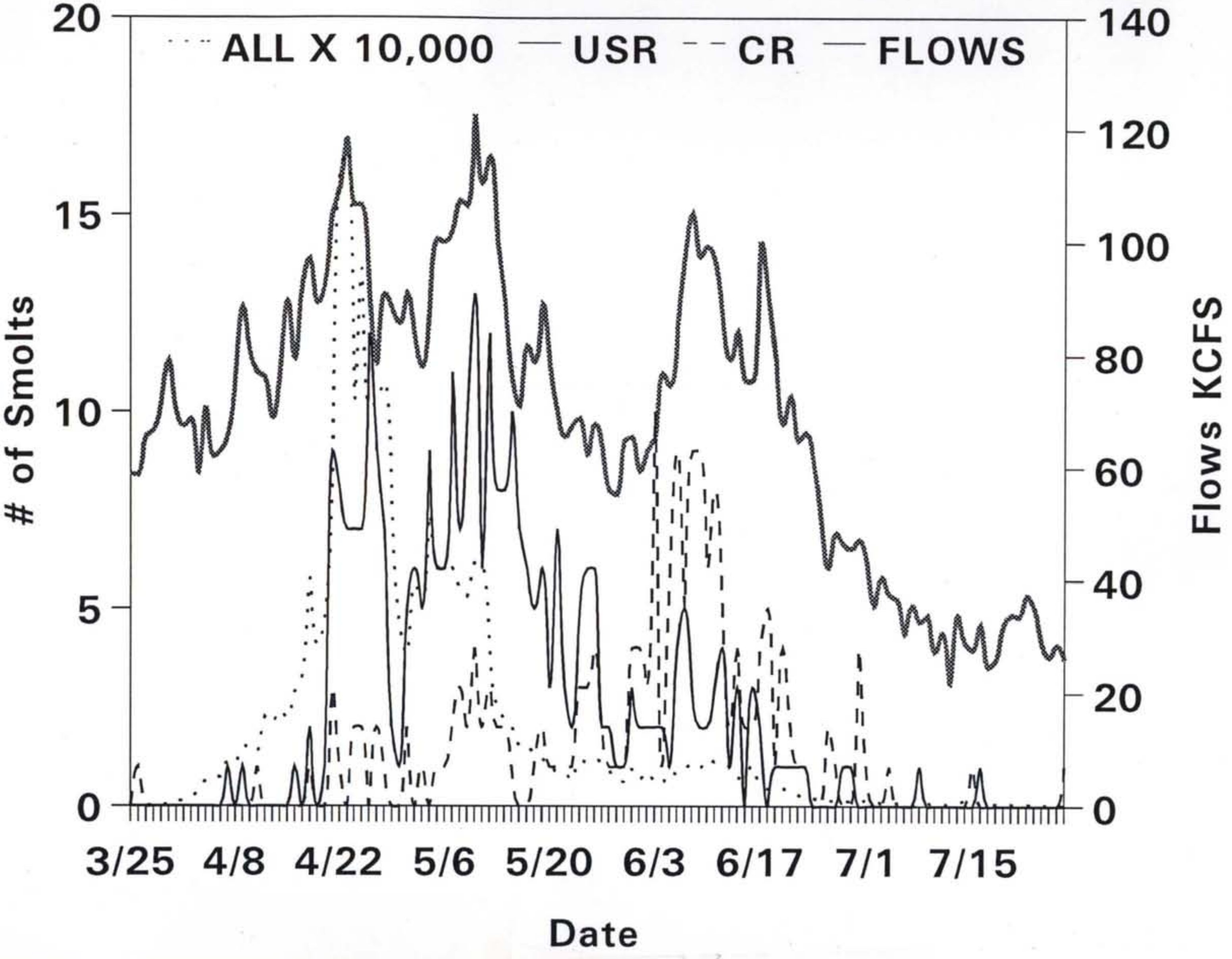

Figure 9. 1989 chinook smolt runs and flows at LGR dam.

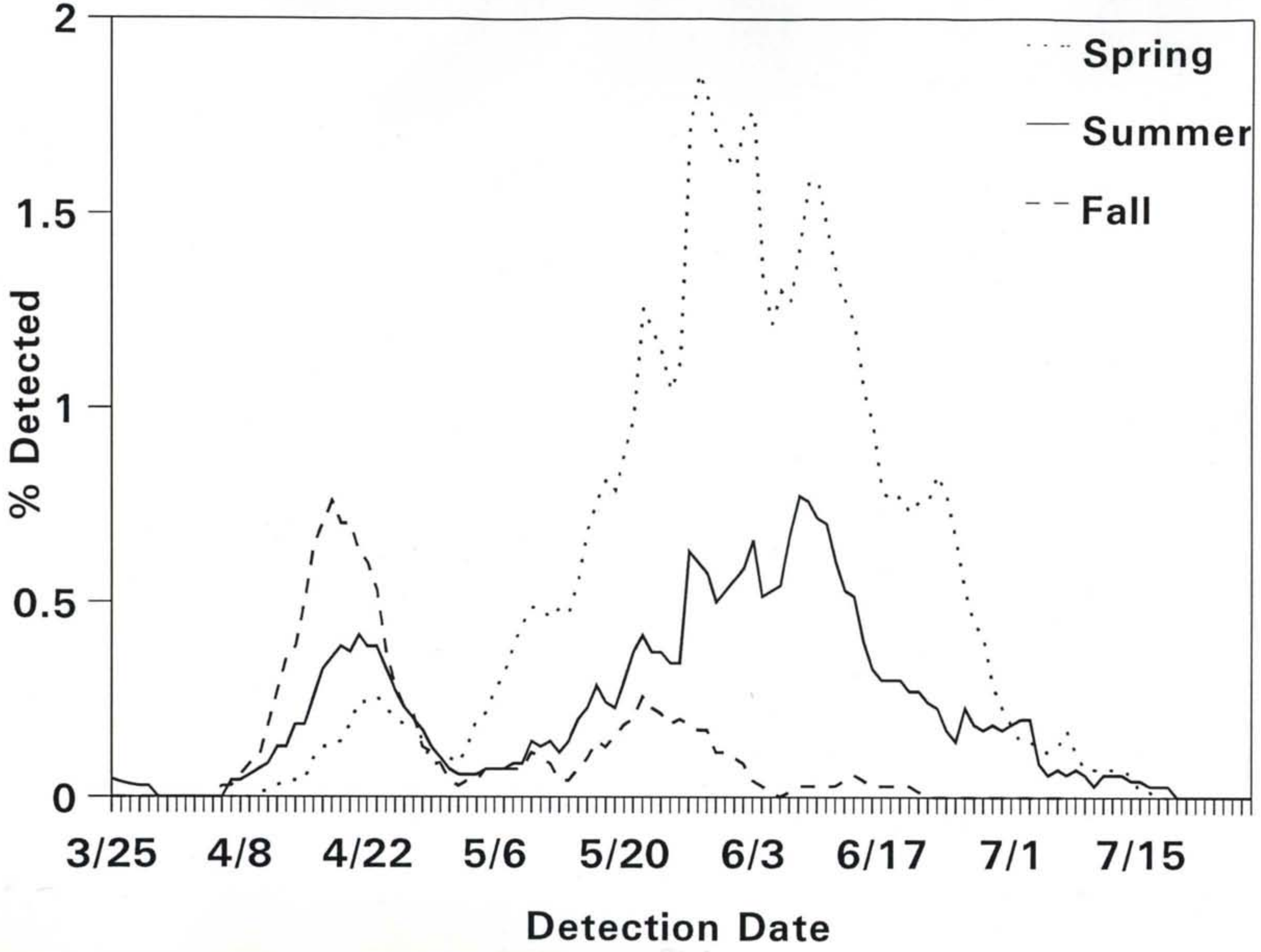

Figure 10. Crooked River chinook PIT tag detections at LGR dam by season of tagging (7 day moving averages of 1989-1991 data).

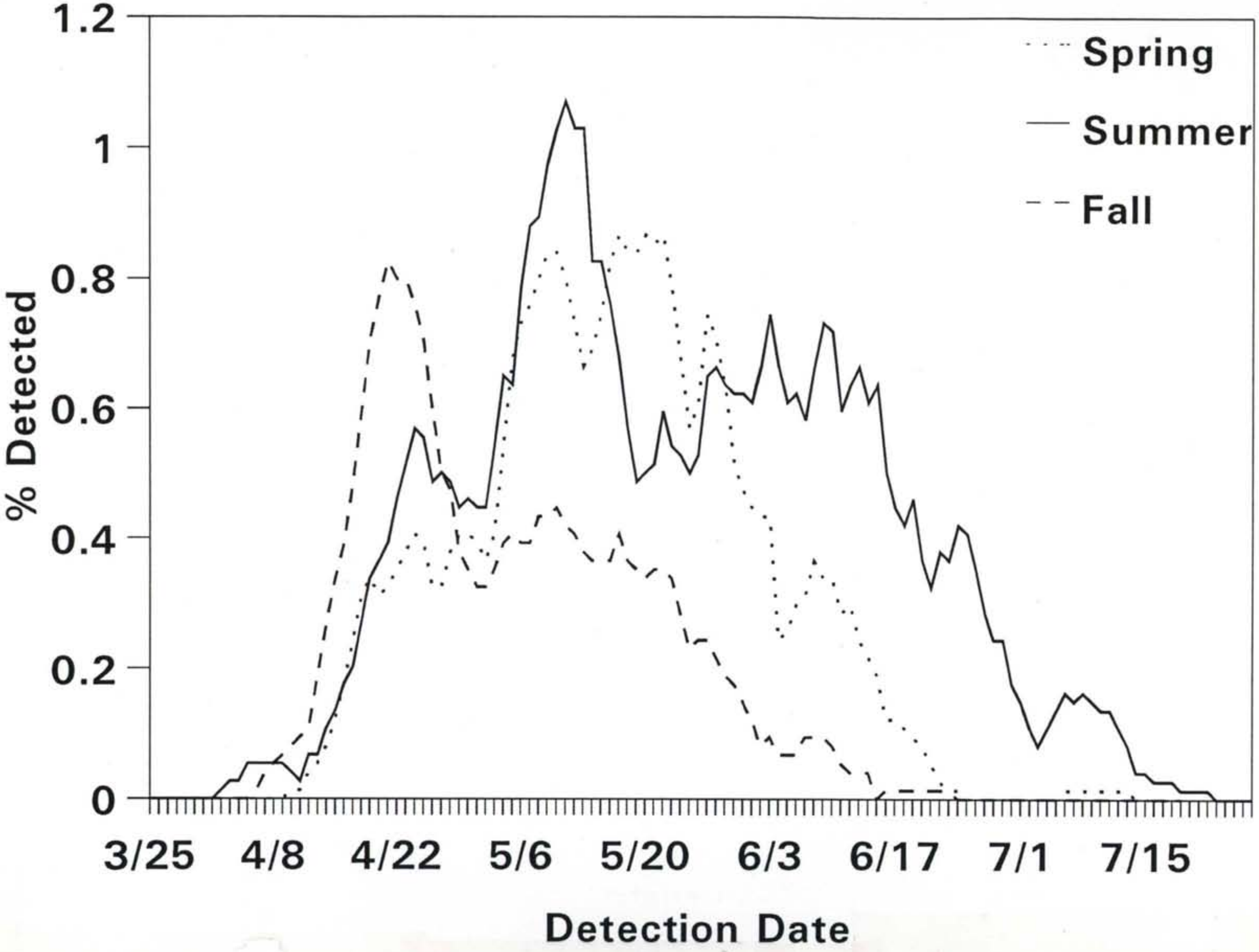

Figure 11. Upper Salmon River PIT tag detections at LGR dam by season of tagging (7 day moving averages of 1989-1991 data).

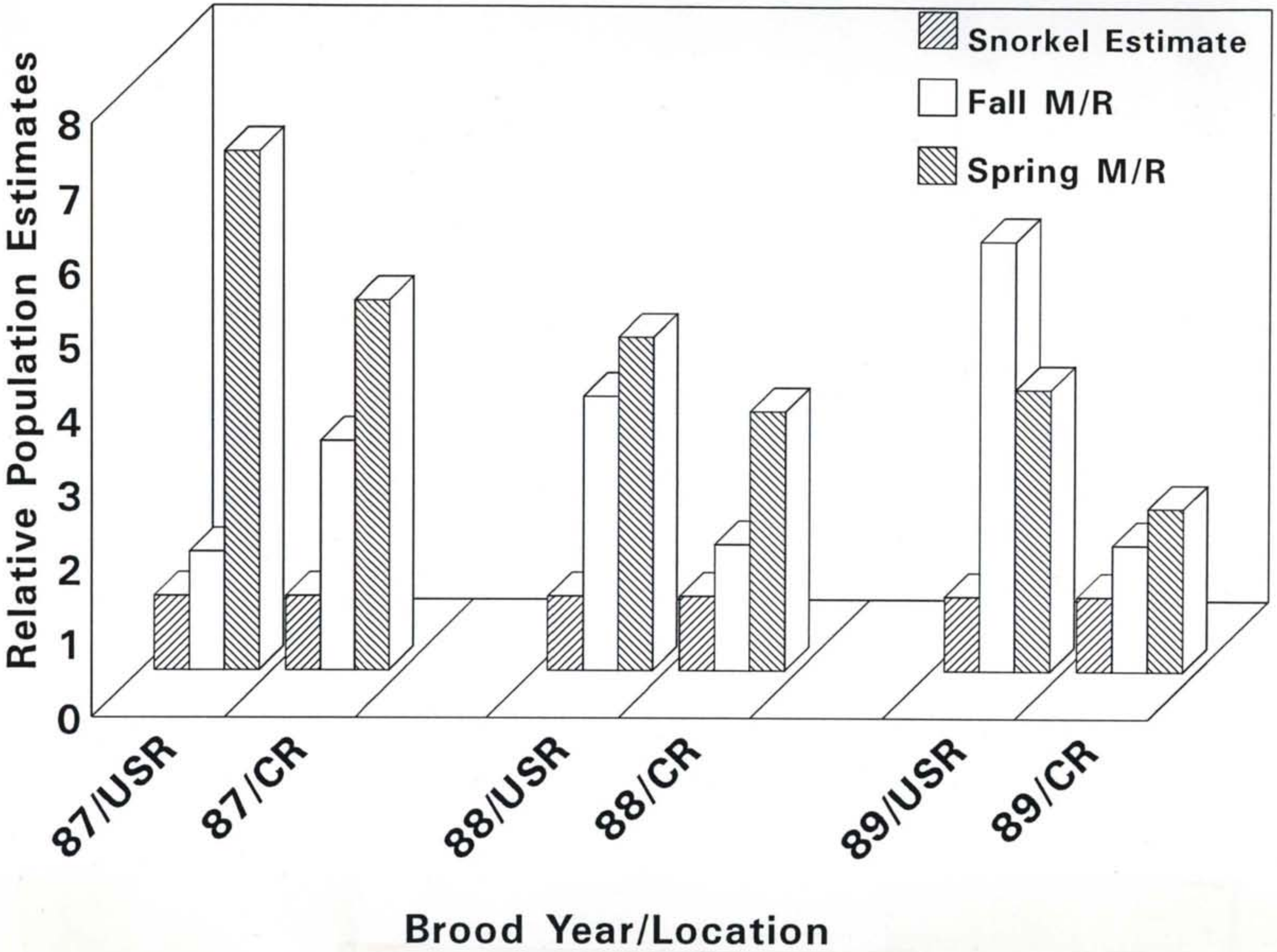

Figure 12. Comparison of snorkel count and PIT tag Peterson Mark/Recapture chinook population estimates.

Table 1. Comparison of Snorkel Count and Peterson Mark-Recapture (M/R) Chinook Parr Population Estimates.

BY/Site	Method	No. Marked in August	No. Captured by Trap	No. Recaptured by Trap	Population Estimate	95% C.I. (±)
87/USR	SNORKEL	-	-	-	88,103	43,772
87/USR	FALL M/R	3,139 (a)	4,732	106	138,820	13,457
87/USR	SPRING M/R	4,634	666	4	617,249	384,620
87/CR	SNORKEL	-	-	-	60,509	19,831
87/CR	FALL M/R	2,481	6,778	89	186,847	19,896
87/CR	SPRING M/R	2,481	2,911	23	300,925	65,216
88/USR	SNORKEL	-	-	-	155,607	44,684
88/USR	FALL M/R	2,538 (a)	9,479	41	572,802	91,440
88/USR	SPRING M/R	5,398	1,942	14	698,861	199,397
88/CR	SNORKEL	-	-	-	101,947	34,196
88/CR	FALL M/R	3,847	2,679	60	168,953	21,925
88/CR	SPRING M/R	3,847	3,667	39	352,674	57,612
89/USR	SNORKEL	-	-	-	23,918	10,085
89/USR	FALL M/R	492 (a)	1,400	4	137,760	85,977
89/USR	SPRING M/R	1,075	420	4	90,300	56,168
89/CR	SNORKEL	-	-	-	9,893	1,742
89/CR	FALL M/R	747	681	29	16,957	3,187
89/CR	SPRING M/R	747	204	6	21,770	10,215

(a) - Only includes parr tagged below Busterback diversion because dewatering at this diversion was a migration barrier to fall emigrants.

Summary

1. In general, a higher-elevation stream will have a higher proportion of its juvenile chinook population emigrate in the fall, and the peak of fall emigration will occur earlier.

2. The proportion of the population emigrating in the fall is fairly consistent year to year for a given stream, irrespective of as much as a tenfold change in population levels.

3. The major stimuli for fall emigration are significant decreases in water temperature, and new moon phases. A significant increase in discharge is the major stimulus for emigration in the spring.

4. Data from this project and from the National Marine Fisheries Service (NMFS; Mathews et al. 1992) indicates that each stock of naturally produced spring chinook has its own apparently genetically controlled migration timing to LGR dam, and that most naturally produced smolts arrive later than the more numerous hatchery smolts.

5. For naturally produced spring chinook juveniles tagged by this project and by NMFS (Mathews et al. 1990), all major peaks in arrival of smolts at LGR dam correspond with peaks in flows at LGR dam.

6. Efforts to improve migration rates and survival of naturally produced spring chinook smolts through the lower Snake River hydroelectric system must occur during the entire smolt migration season in order to protect all naturally produced stocks.

7. Our data indicates that there may be significant delayed mortality of summer PIT tagged chinook parr. We recommend caution in using PIT tagging to estimate survival rates until this question is answered.

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Migration Characteristics and Survival of Hatchery-Reared Chinook Salmon Smolts Released in the Grande Ronde and Imnaha River Basins

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Introduction

Spring and summer chinook salmon *Oncorhynchus tshawytscha* populations in northeastern Oregon have declined precipitously since the late 1940s. Peak escapement, as indexed by annual redd counts, occurred in 1957 when 21.1 redds/m were observed (Thompson and Haas 1960). Spawner escapement remained fairly stable from 1964 to 1973 (range 6.5-10.8 redds/m), after which it dropped sharply in 1974 and remained severely depressed (Carmichael 1990). Population declines have been attributed to reduced population productivity resulting from juvenile and adult mortality that occurs during migration to and from the ocean.

Hatchery facilities have been constructed and propagation programs implemented in Oregon under the Lower Snake River Compensation Plan (LSRCP) to mitigate for losses of chinook salmon and summer steelhead *O. mykiss* in the Grande Ronde and Imnaha river basins (United States Army Corps of Engineers 1975). Production of hatchery fish in Oregon under the LSRCP began in 1982. The success of the hatchery program has been highly variable and generally poor (Carmichael et al. 1991).

Migration characteristics and survival of chinook salmon smolts in the Snake River basin have been the focus of numerous studies and much debate in the past decade (Giorgi 1991). Migration timing information for hatchery smolts has been used extensively to develop flow and passage recommendations in the Snake River. Poor migration success of hatchery smolts from release sites to Lower Granite Dam, the first dam encountered during seaward migration, is considered a principal factor in the poor performance of the hatchery programs (Carmichael et al. 1991).

We have been conducting experiments to determine optimum rearing and release strategies for chinook salmon hatchery production at Lookingglass Hatchery and in the Imnaha River. As part of our hatchery effectiveness studies we have been investigating smolt migration characteristics and survival. In this paper we present a summary of smolt migration characteristics and survival to Lower Granite Dam for hatchery smolts released from Lookingglass Hatchery and into the Imnaha River. We have focused on three aspects of smolt performance:

1. Comparing relative migration success to Lower Granite Dam between years and stocks.
2. Comparing smolt migration patterns at Lower Granite Dam between release strategies, stocks, and years.
3. Characterizing length frequency changes that occur from time-of-release to time-of-recapture at Lower Granite Dam.

This information is provided to further the understanding of the migration characteristics and performance of hatchery chinook salmon smolts in the Snake River Basin and provide a basis for comparison with wild stocks and other hatchery stocks.

Study Area

Lookingglass Hatchery is located in the Grande Ronde Basin at km 4.0 on Lookingglass Creek. Lookingglass Creek enters the Grande Ronde River at km 136.9 and the total distance from Lookingglass Hatchery to Lower Granite Dam is 239.4 km. The Imnaha River facility is located at km 85.3 on the

Imnaha River. The Imnaha River enters the Snake River at 135.5 km above Lower Granite Dam. Lower Granite Dam is located at km 173.8 on the Snake River and is 690 km from the ocean.

Methods

Hatchery fish used in these studies were produced at Lookingglass Hatchery (Figure 1). Smolts released in the Imnaha River were primarily progeny of wild adults collected from the Imnaha River. Smolts released at Lookingglass Hatchery were progeny of Rapid River stock that had been obtained from Idaho hatcheries or had returned to Lookingglass Hatchery. We branded and released replicate groups of 25,000 of 1985-1989 brood Imnaha stock smolts and 1986-1989 brood Rapid River smolts. Smolts were released as age 1+ fish in the spring. Branding was conducted during the fall prior to the spring of release. Brand retention checks were conducted within two weeks of release to determine the number of recognizably branded fish. Length frequency distributions were determined just prior to release for each group.

Migration timing and survival was determined from recovery of branded smolts at Lower Granite Dam, which is located on the Snake River 696 km from the mouth of the Columbia River. Fish entering the powerhouse intakes are guided into a bypass system. Fish that enter the bypass system are subsampled to enumerate brands (Fish Passage Center 1991). Because fish guidance efficiency is variable, dependent on flow and time of year and not determined each year, the estimated survival must be considered an index and not an absolute estimate. Survival indices were calculated as the proportion of recognizably branded fish released that were estimated to have entered the bypass facility or traveled over the spillway at Lower Granite Dam. We pooled release and recovery data for replicate brands. Data is presented for a variety of release strategies that are being evaluated.

Results and Discussion

Migration success to Lower Granite Dam for smolts released at Lookingglass Hatchery varied considerably for the 1988-1991 migration years (Figure 2). Passage indices ranged from a low of 8.0% for smolts released in 1989 to a high of 32.9% for smolts released in 1991. Migration success of smolts released at approximately 23.0 g was similar to the migration success of smolts released at approximately 38.0 g. Migration success of Imnaha stock smolts also varied considerably from year to year (Figure 2). Smolt passage indices ranged from 4.6% for smolts released in 1987 to 22.6% for smolts released in 1991. Smolt passage indices for Rapid River stock smolts released at Lookingglass Hatchery were greater than passage indices for Imnaha stock smolts released in the Imnaha River in all years except 1989 (Figure 2). Similar migration success has been previously reported for other hatchery smolts released in Idaho tributaries of the Snake River (Fish Passage Center 1990, 1991 and Mathews et al. 1990).

We were unable to determine exact survival rates from release locations to Lower Granite Dam. Fish guidance efficiencies at Lower Granite Dam were not estimated each year to provide expansion factors for fish that passed through the dam via the turbines. Fish guidance efficiencies were estimated to be 50% in 1984, 52% in 1985, 53.4% in 1986 (Ledgerwood et al. 1987), and 57.3% in 1989 (Swan et al. 1990). Given fish guidance efficiencies of slightly over 50% and passage indices less than 25% in most years, it appears that less than 50% of the hatchery smolts released from Lookingglass Hatchery and into the Imnaha River arrive at Lower Granite Dam in most years. We are uncertain whether losses are a result of direct mortality after release, mortality during migration, or residualization. Carmichael et al. (1991) reported that smolt-to-adult survival rates for hatchery reared chinook smolts released at Lookingglass Hatchery and into the Imnaha River were generally poor and highly variable from year to year. The low and highly variable smolt migration success is probably a contributing factor to poor and variable smolt-to-adult survival rates reported by Carmichael et al. (1991).

Smolts released from Lookingglass Hatchery from 1988-1991 initially reached Lower Granite Dam 6 to 12 days after release (Figures 3-6). Migration peaked from 18 to 30 days after release. Migration was nearly completed within 47 days after release in all years; however in 1989 and 1991, small numbers of fish did not arrive at Lower Granite Dam until 63 days after release. Smolts released into the Imnaha River from

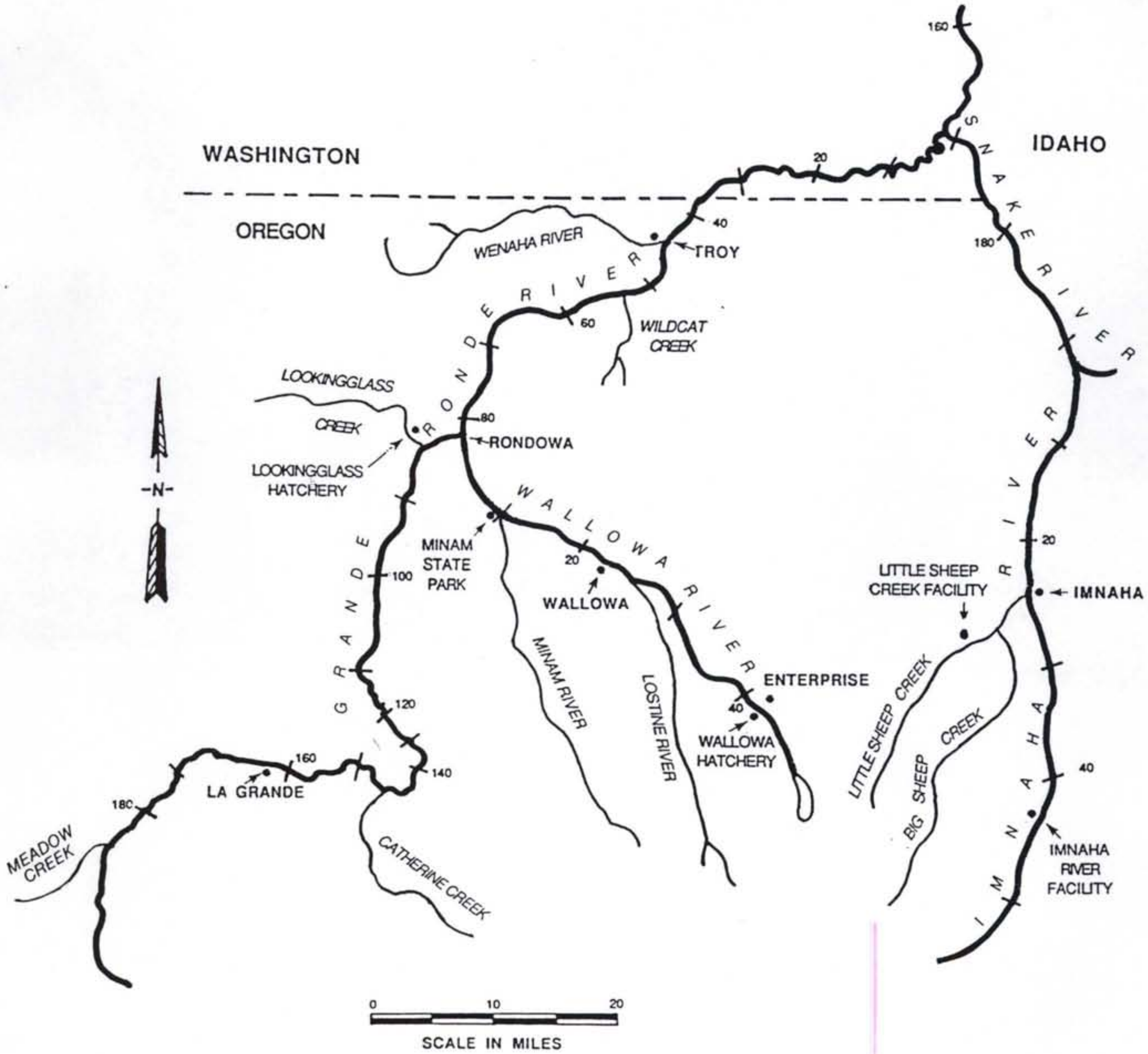


Figure 1. Map of northeast Oregon showing locations of Lower Snake River Compensation Plan hatchery facilities.

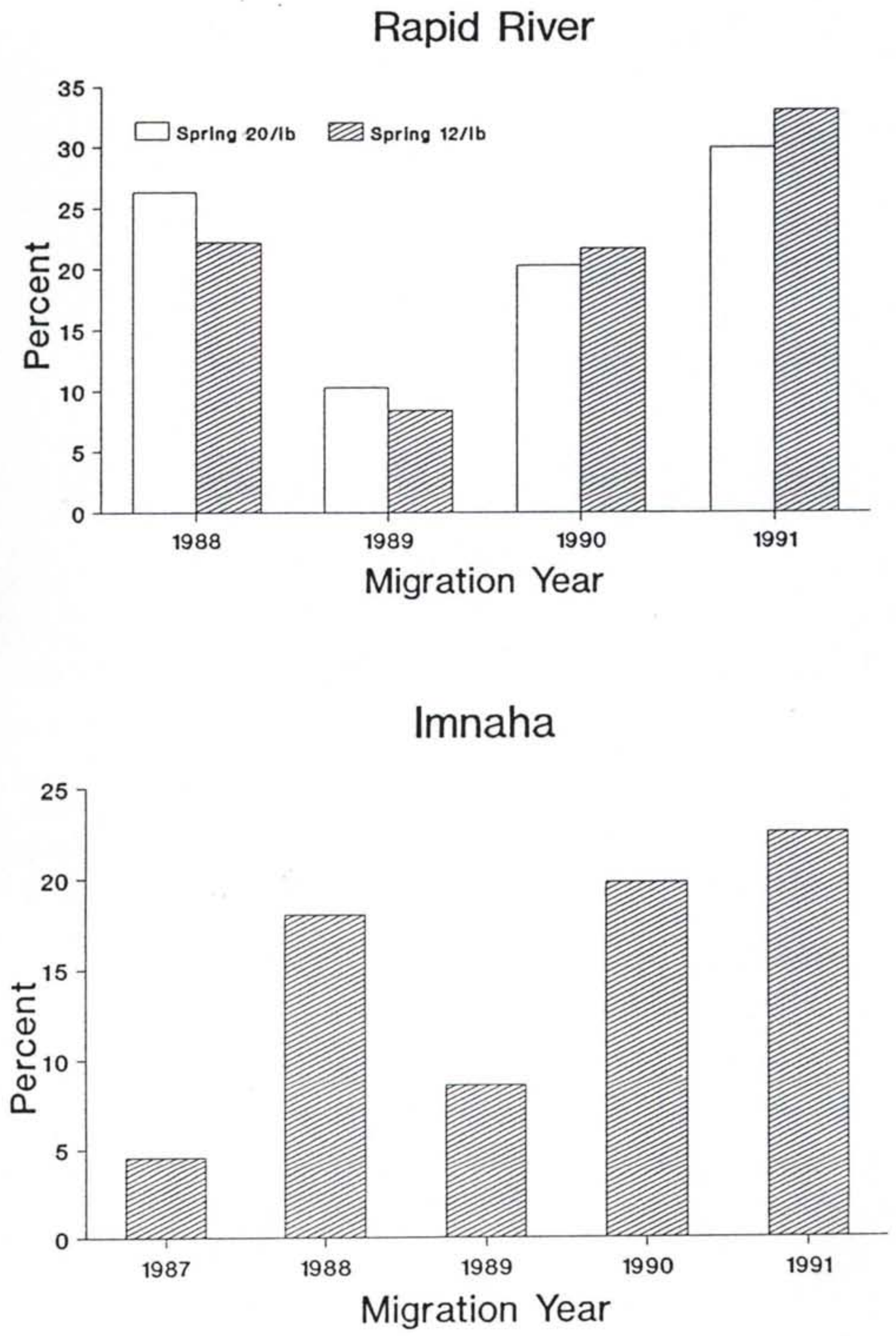


Figure 2. Survival indices at Lower Granite Dam for Rapid River stock spring chinook salmon hatchery smolts released at different sizes from Lookingglass Hatchery and for Imnaha stock hatchery smolts released into the Imnaha River.

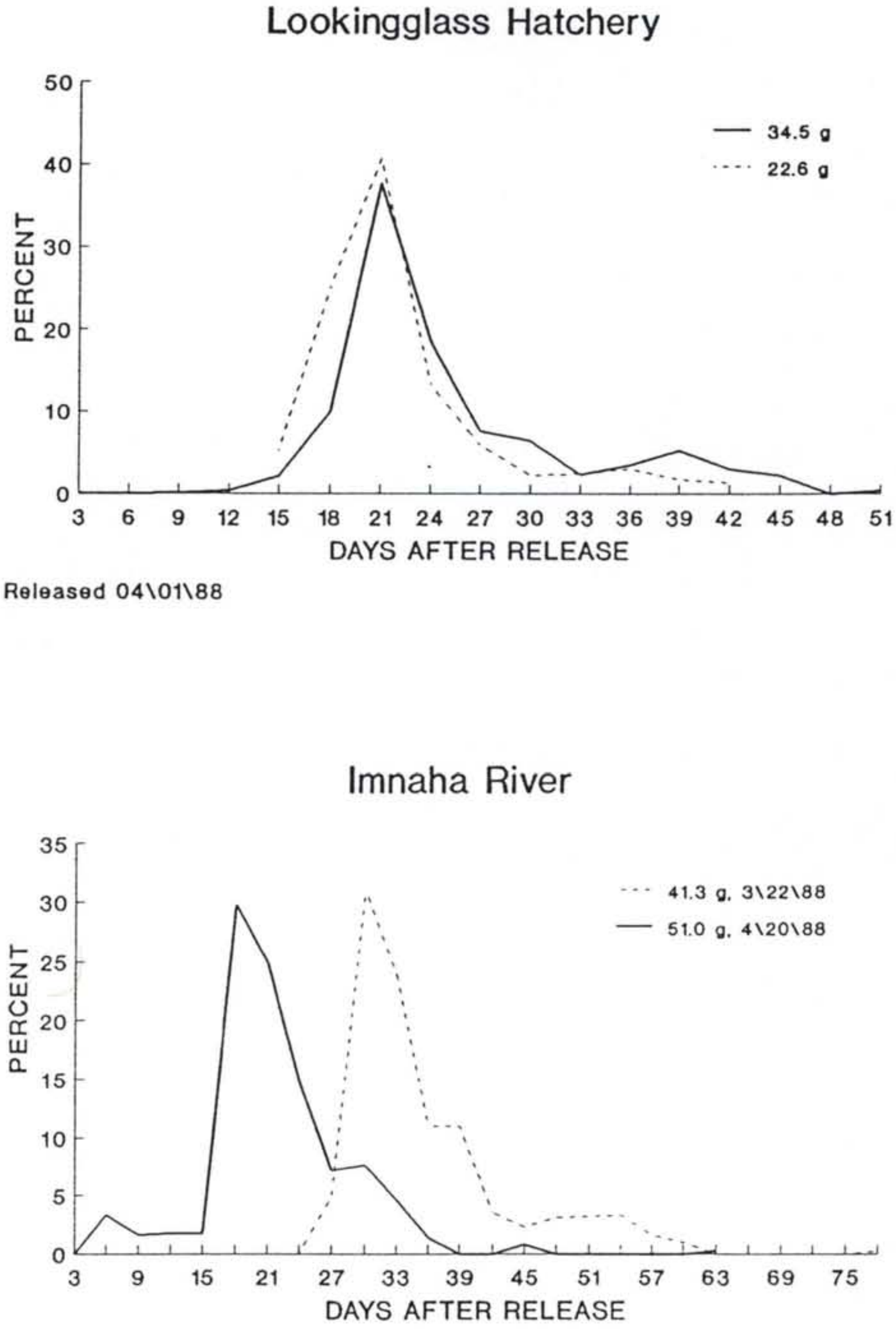
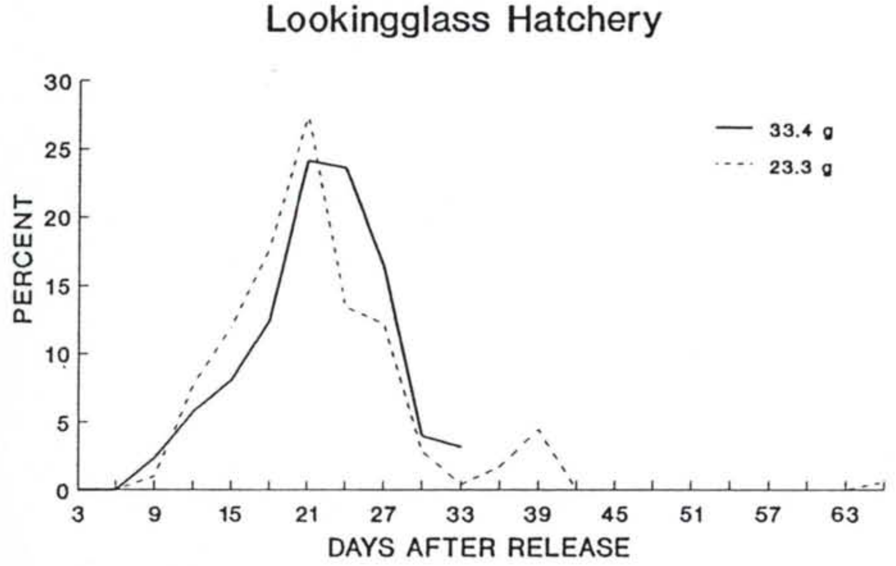


Figure 3. Migration timing at Lower Granite Dam during 1988 for 1986 brood Rapid River stock hatchery smolts released at different sizes from Lookingglass Hatchery and for 1986 brood Imnaha stock hatchery smolts released into the Imnaha River.



Lookingglass Hatchery

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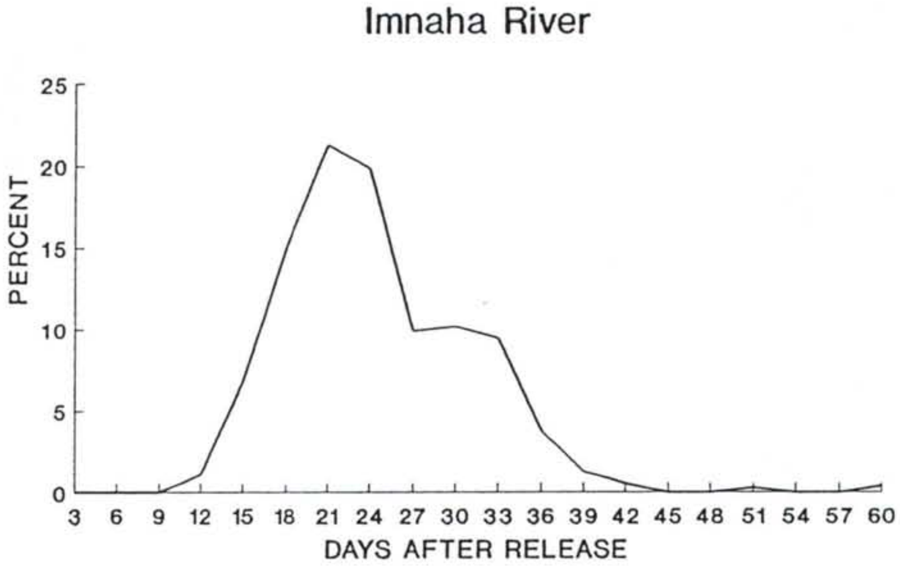

Imnaha River

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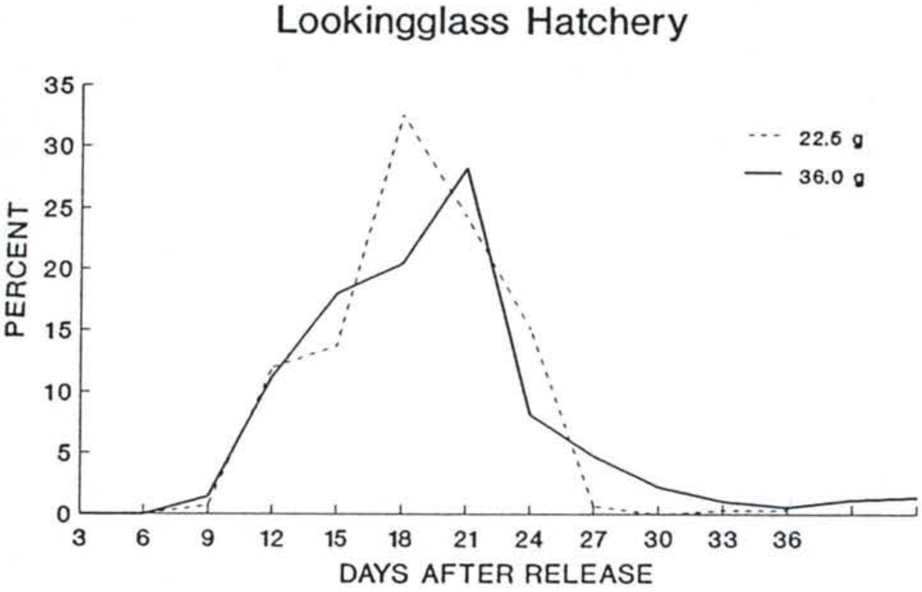
Figure 4. Migration timing at Lower Granite Dam during 1989 for 1987 brood Rapid River stock hatchery smolts released at different sizes from Lookingglass Hatchery and for 1987 brood Imnaha stock hatchery smolts released into the Imnaha River.



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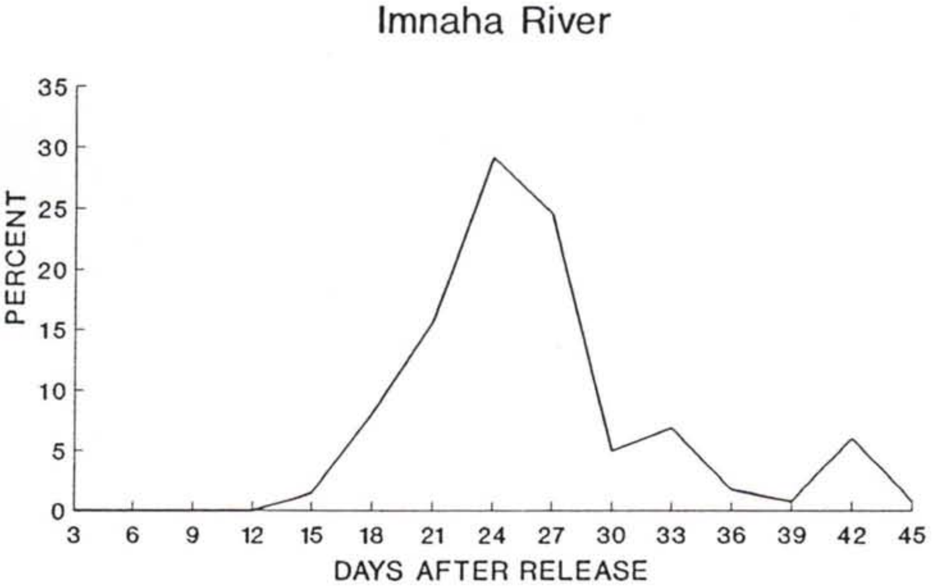

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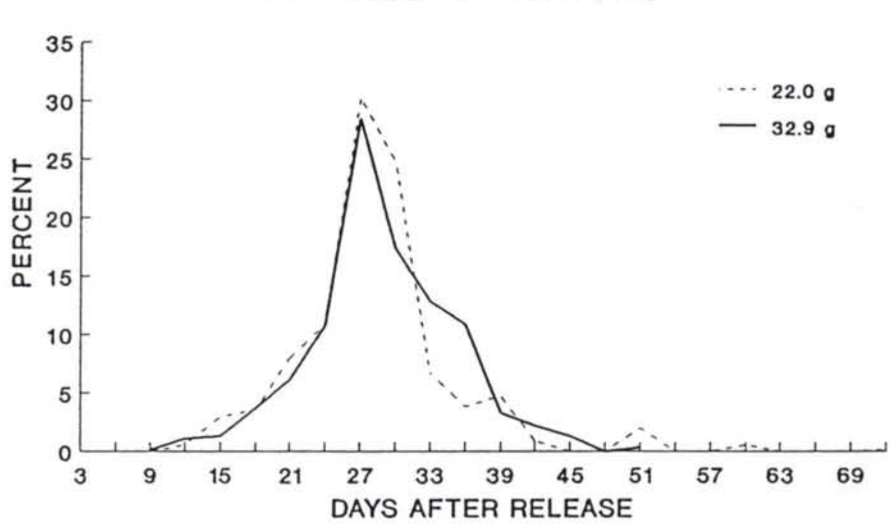
Figure 5. Migration timing at Lower Granite Dam during 1990 for 1988 brood Rapid River stock hatchery smolts released at different sizes from Lookingglass Hatchery and for 1988 brood Imnaha stock hatchery smolts released into the Imnaha River.



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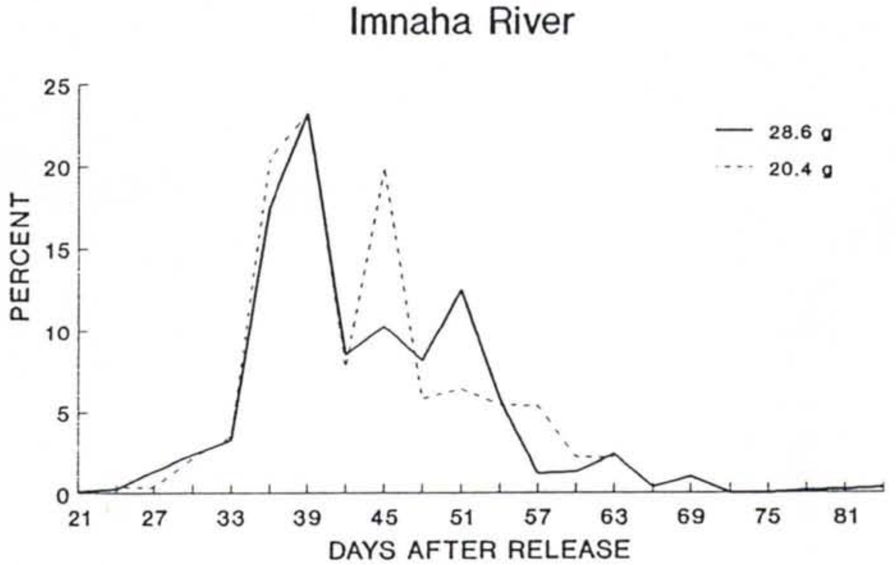

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Figure 6. Migration timing at Lower Granite Dam during 1991 for 1989 brood Rapid River stock hatchery smolts released at different sizes from Lookingglass Hatchery and for 1989 brood Imnaha stock hatchery smolts released into the Imnaha River.

1988-1991 initially reached Lower Granite Dam 4 to 21 days after release. Smolt migration peaked 17 to 45 days following release and the majority of smolts arrived within 60 days after release. Migration was not completed until 81 days after release in 1991. The peak of migration for smolts released into the Imnaha River was later than the peak for smolts released at Lookingglass Hatchery even though the Imnaha release location is closer to Lower Granite Dam. Migration was more prolonged for the Imnaha stock smolts.

We observed little change in length frequency distribution from time of release to time of recapture at Lower Granite Dam for either Rapid River stock smolts or Imnaha stock smolts (Figures 7-10). Length frequencies shifted approximately 10mm in most cases with the exception of Imnaha stock smolts released in 1990 and 1991. We observed greater length frequency shifts in these two years. Small changes in length frequency indicate that little growth is achieved during migration for yearling smolts. In contrast, Zaugg et al. (1986) and Carmichael and Messmer (1990) reported significant length frequency increases and growth during migration for hatchery reared subyearling spring chinook smolts. Subyearling smolts migrated later than yearling smolts during periods when river temperatures were substantially warmer.

Conclusions

1. Migration success to Lower Granite Dam was highly variable and generally poor for all groups of branded yearling smolts released at Lookingglass Hatchery and into the Imnaha River from 1987-1991.

2. Poor smolt migration success is a significant factor contributing to low smolt-to-adult survival rates observed for Snake River hatchery reared spring/summer chinook salmon.

3. Research and monitoring activities should be initiated to determine magnitude, location, and causes of loss for hatchery reared smolts above Lower Granite Dam and to determine losses of naturally produced smolts during migration.

4. Improving smolt migration success with flow and passage improvements in the Snake River is critical to improving hatchery success and recovering depressed natural populations.

5. The peak of migration at Lower Granite Dam of smolts released at Lookingglass Hatchery and into the Imnaha River was well after the release date and migration duration was prolonged.

6. In most years, the peak of migration was later and migration duration was longer for smolts released in the Imnaha River in comparison to smolts released at Lookingglass Hatchery.

7. It appears that little growth is achieved for yearling hatchery reared chinook smolts during migration through the Snake River above Lower Granite Dam.

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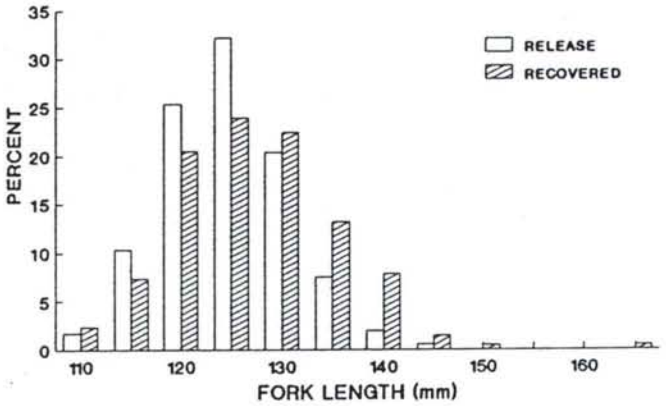
Lookingglass Hatchery



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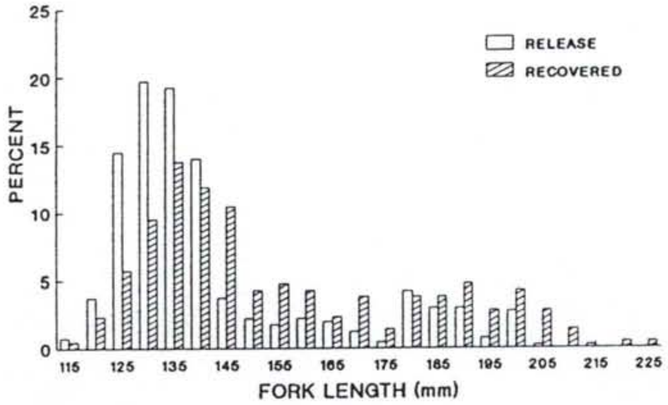
Lookingglass Hatchery



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Imnaha

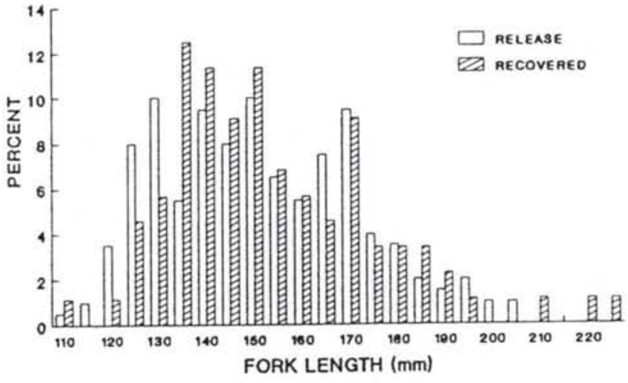

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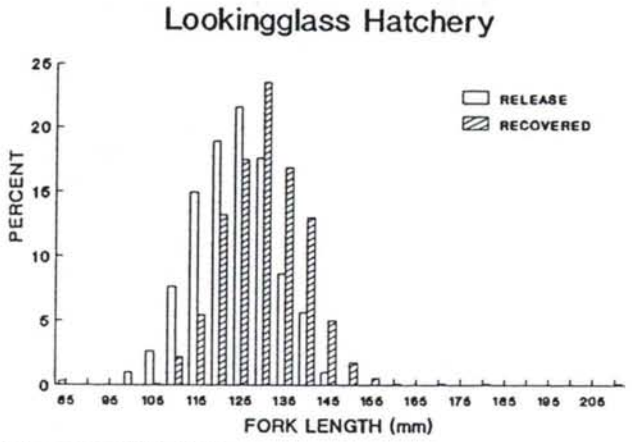
Figure 7. Length frequency at release and at recapture at Lower Granite Dam for 1986 brood Rapid River stock spring chinook salmon hatchery smolts released at different sizes from Lookingglass Hatchery and for 1986 brood Imnaha stock hatchery smolts released into the Imnaha River.


Lookingglass Hatchery

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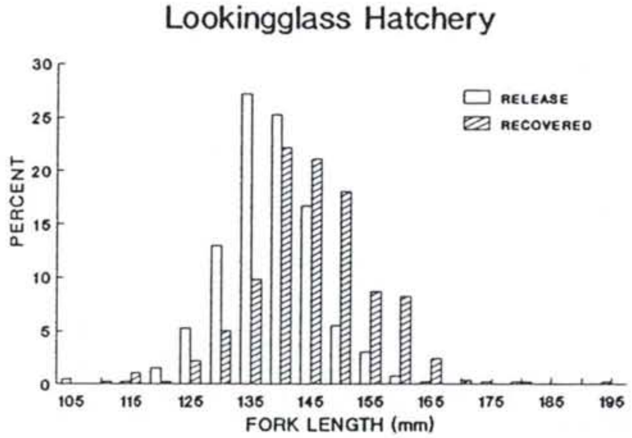
Lookingglass Hatchery

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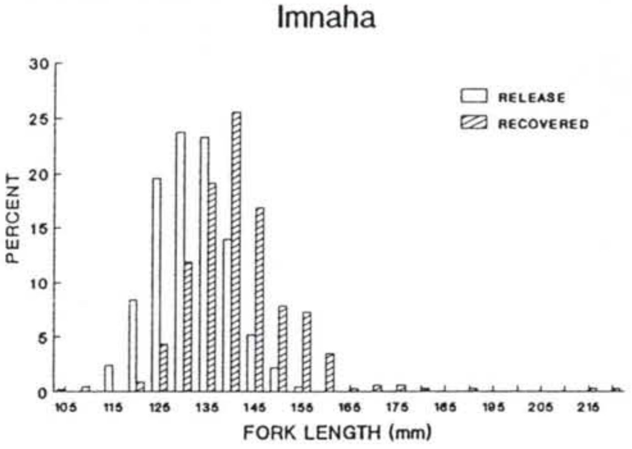
Imnaha

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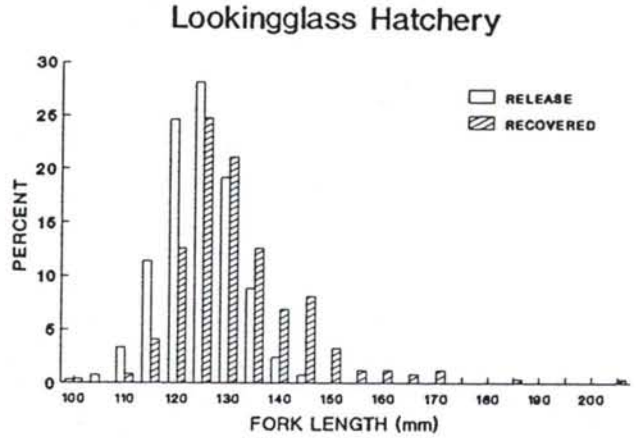
Figure 8. Length frequency at release and at recapture at Lower Granite Dam for 1987 brood Rapid River stock spring chinook salmon hatchery smolts released at different sizes from Lookingglass Hatchery and for 1987 brood Imnaha stock hatchery smolts released into the Imnaha River.



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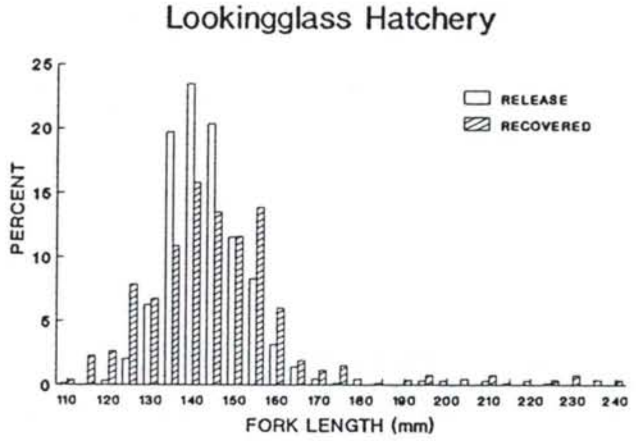

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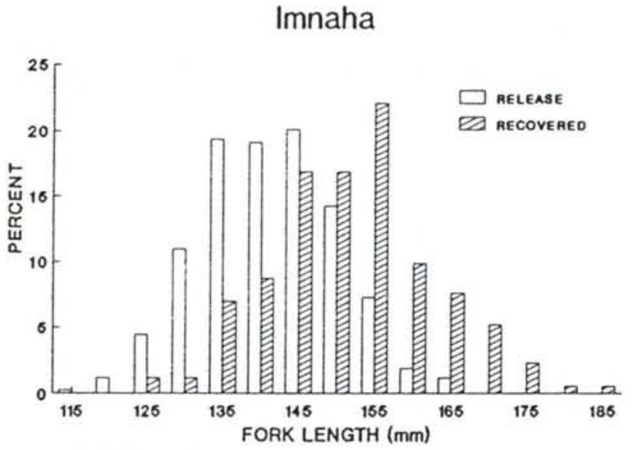

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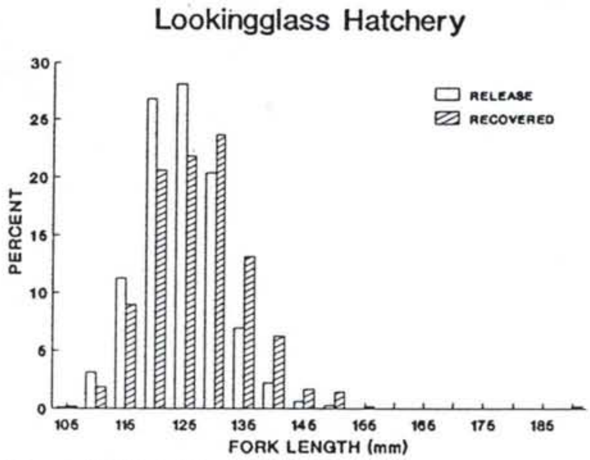
Figure 9. Length frequency at release and at recapture at Lower Granite Dam for 1988 brood Rapid River stock spring chinook salmon hatchery smolts released at different sizes from Lookingglass Hatchery and for 1988 brood Imnaha stock hatchery smolts released into the Imnaha River.



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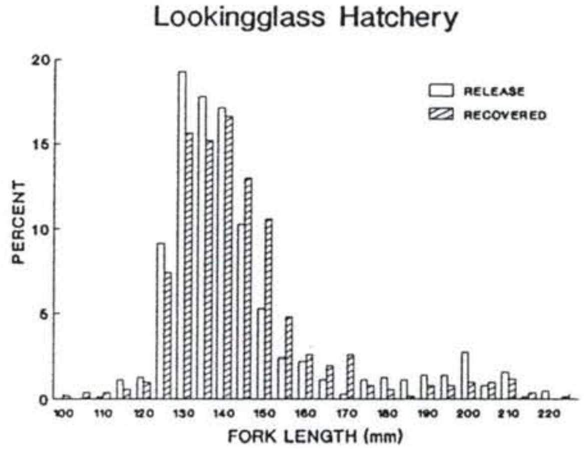

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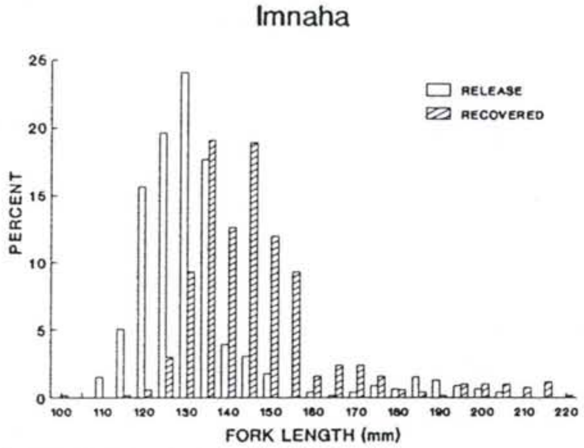

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Figure 10. Length frequency at release and at recapture at Lower Granite Dam for 1989 brood Rapid River stock spring chinook salmon hatchery smolts released at different sizes from Lookingglass Hatchery and for 1989 brood Imnaha stock hatchery smolts released into the Imnaha River.

Migration Timing of Natural and Hatchery Fall Chinook in the Snake River Basin

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Introduction

Information pertaining to natural Snake River fall chinook salmon *Oncorhynchus tshawytscha* fry behavior and outmigration timing prior to the 1957 construction of Brownlee Dam is limited to 1956 trapping data collected by the Idaho Department of Fish and Game (IDFG) in the vicinity of Pleasant Valley (Bell 1957). These data showed a dispersal of 51- to 85-mm parr during May when the traps were operated.

In the first few years after Brownlee Dam was completed, IDFG traps were run almost 12 months of the year to monitor the efficiency of Brownlee Reservoir fish barriers that were intended to intercept downstream migrating salmonids. These postdam data, although inconclusive, suggested a bimodal migration pattern consisting of parr dispersal in April and May and smolt outmigration from June through September (Bell 1960).

Immediately after the completion of Oxbow Dam in 1961, fall chinook management and research emphasis shifted towards hatchery mitigation. As time passed from the mid-1960s through the 1970s and into the 1980s, six more mainstem Snake River dams were completed and Snake River fall chinook had been propagated in almost as many different hatcheries. Lyons Ferry Hatchery became operational in 1984 and has served as the main fall chinook propagation facility to date.

During the 30-year period of Snake River impounding and hatchery propagation efforts, a varying number of fall chinook adults continued to spawn in the regulated Snake River. By the time Lyons Ferry Hatchery was completed in 1984, only 166 km of flowing river below Hells Canyon Dam remained available for natural production. The Anatomy of a River Study in the mid-seventies focused on the needs of naturally produced fall chinook in this reach of river (Bayha 1974); however, study recommendations were largely ignored and traded off for more hatchery mitigation.

Snake River flows for chinook smolt outmigration are provided by the April 15 to June 15 Water Budget. In the past it has been difficult to assess the benefits of these releases on natural fall chinook survival because of the absence of current early life history data. With this fact in mind, we began an interagency study of juvenile fall chinook produced naturally in the Snake River below Hells Canyon Dam in 1991. The objective of this paper is to present and compare the most current information on fry behavior and smolt migrational characteristics of Lyons Ferry Hatchery and Snake River natural fall chinook salmon. We found survival data far too provisional to allow conclusive analysis at this time. On the other hand, in the spirit of this workshop, we hoped to spark some stimulating discussion with regard to the implication of these data for modern-day Snake River fall chinook salmon smolt survival.

Study Area

Lyons Ferry Fish Hatchery is located on the Snake River between Lower Monumental and Little Goose Dams at river kilometer (RK) 95 (Figure 1). Data from natural fall chinook salmon were collected from the head of Lower Granite Reservoir (RK 225) to the mouth of Red Bird Creek (RK 250) (Figure 1).

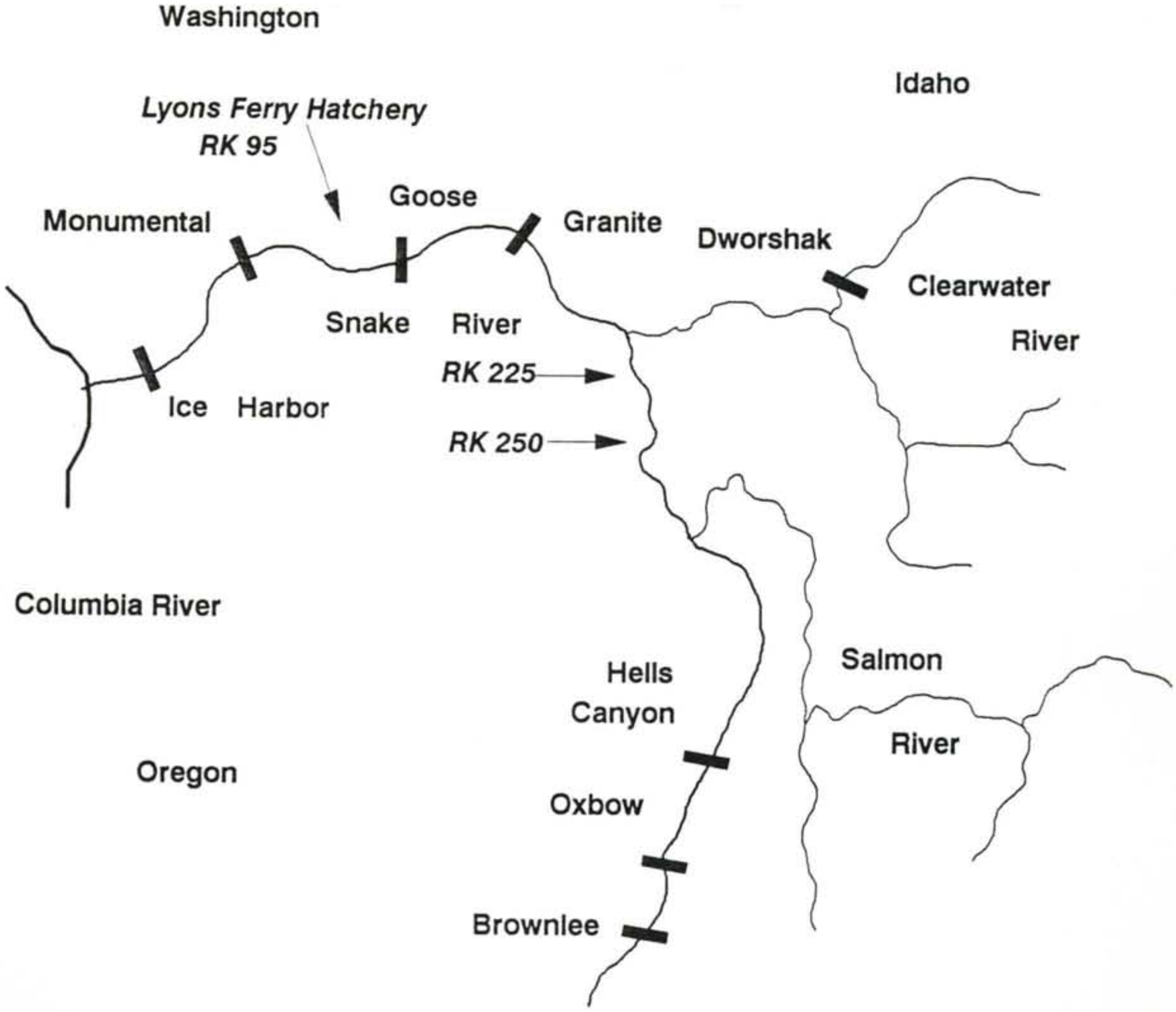

Figure 1. Lyons Ferry Hatchery and natural Snake River fall chinook salmon study area.

Methods

We summarized information pertaining to Lyons Ferry Hatchery fall chinook salmon from published 1990 data (Bugert et al. 1991). We refer to Lyons Ferry as the "hatchery" for the remainder of this document.

Data for naturally produced fall chinook were summarized from Connor et. al. (Draft). These data were collected in 1991 by the use of beach seines and Passive Integrated Transponders (PIT) tags (Prentice et al. 1990). We calculated incubation and growth rates based on Snake River water temperature and, in turn, used the rates to estimate a size range for fall chinook salmon. Salmon seined within this size range were believed to be natural Snake River fall chinook. When our PIT-tagged salmon passed Lower Granite Dam they were detected, diverted, and held in live wells until they reached 130 mm. The Washington Department of Fisheries (WDF) analyzed the 130-mm salmon by electrophoresis to validate their race. We refer to fall chinook salmon juveniles as "salmon" for the remainder of this document.

Results

Early Life History

Spawning and incubation.—Fall chinook salmon spawning at Lyons Ferry Hatchery starts in mid-October with an early to mid-November peak and ends by mid-December (Figure 2). Natural fall chinook spawning is concentrated in mid-November with some spawning taking place in October and December, but not as consistently as in the hatchery.

The hatchery water temperature is fairly constant at about 10°C, while the Snake River water temperature ranges from 10°C during fall chinook salmon spawning to 2°C during egg incubation (Figure 2).

Emergence timing.—Differences in water temperature between Lyons Ferry Hatchery and the Snake River lead to earlier yolk-sac absorption by hatchery salmon than by fish of natural origin (Figure 2). In normal years, hatchery fall chinook "button up" by the end of February, while natural fall chinook salmon fry in the Snake can remain in the gravel as sac-fry as late as May (Figure 3).

Rearing.—Once Lyons Ferry Hatchery salmon absorb their yolk-sacs they are nurtured until ponding. Ponding in 1990 was complete by the end of February. Rearing ponds were supplied with approximately 10°C water from February through May (refer to Figure 2). Lyons Ferry Hatchery focuses primarily on a subyearling release program, so most salmon remain in the ponds for about three months. The low fall chinook salmon escapement to the hatchery over the past eight years has allowed for experimentation with a yearling release program that dictates ponding for about one year.

Natural Snake River fall chinook salmon are reared under variable water temperature conditions from March through July (refer to Figure 2). From late May through July, we seined and tagged a total of 738 salmon of which 486 fit within the size range of natural fall chinook. Our 1991 salmon catch by seine increased from late May to a late June peak, then declined until July 22 when none were captured (Figure 4). A total of 66 PIT-tagged salmon were recaptured, 56 once and 10 twice. Most recaptures occurred in the same site where the salmon were originally tagged. The most common recapture interval was seven days, and intervals ranged up to 26 days (Figure 5).

Size at release.—Lyons Ferry Hatchery size-at-release data from 1990 was representative of most years. Subyearling hatchery fall chinook salmon on-station releases from the Lyons Ferry facility in 1990 averaged 93.4±10.1 mm (Figure 6). Yearling hatchery fall chinook averaged 164.7±8.6 mm at the time of release in 1990 (Figure 6).

Natural fall chinook salmon field work commenced in late May during 1991, so we did not sample emerging fry. Therefore, in calculations of length frequency, the lower tail of the distribution is truncated (Figure 7). Our data, viewed with that of Bell (1957 and 1960), suggests that subyearling fall chinook are usually 52-92 mm in fork length during their period of rearing in the Snake River (Figure 7).

HATCHERY	SPAWN OCT - NOV - DEC 10°C	INCUBATION DEC - JAN - FEB 10°C	REARING PONDS 10°C
NATURAL	SPAWN OCT - NOV - DEC 10°C	INCUBATION DEC - JAN - FEB - MAR - APR - MAY 10 - 2°C	

Figure 2. Life history periodicity estimates for Lyons Ferry Hatchery and natural Snake River fall chinook salmon.

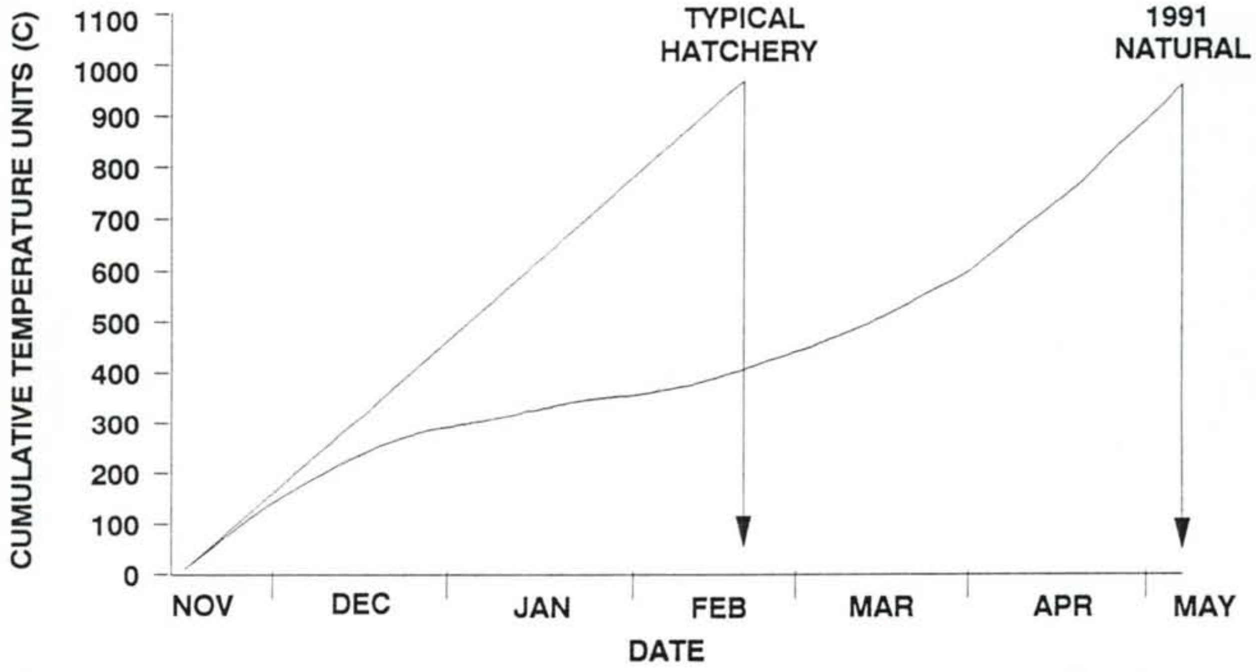

Figure 3. Fall chinook salmon yolk-sac absorption and emergence estimates based on Lyons Ferry Hatchery and Snake River water temperatures, 1990 and 1991.

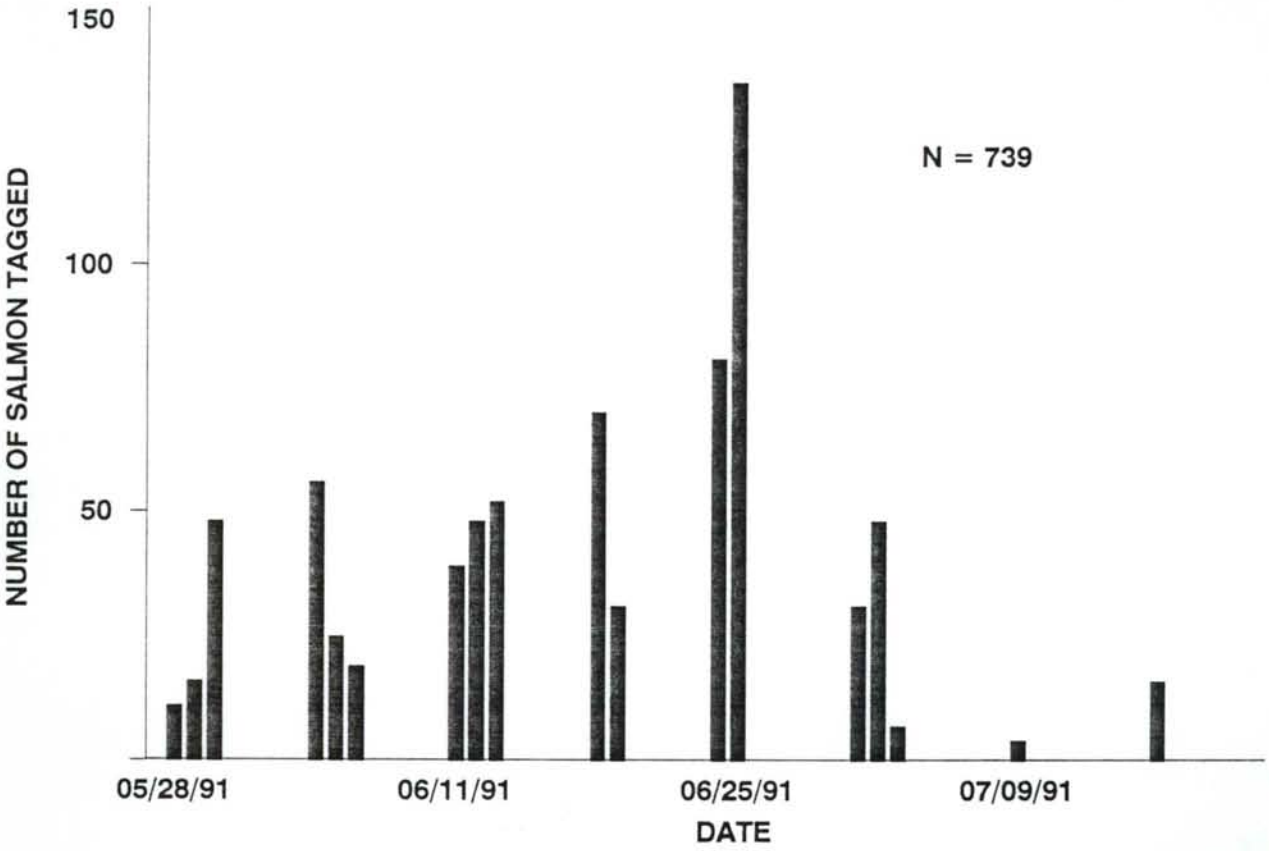

Figure 4. Number of natural chinook salmon PIT tagged in the lower Snake River , 1991

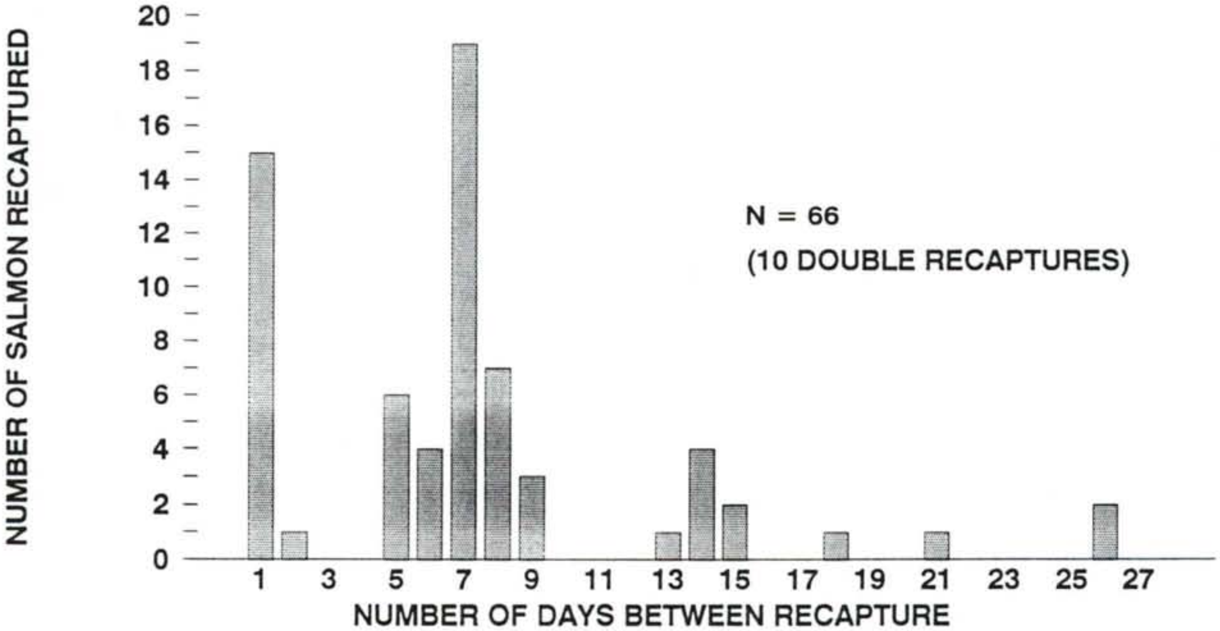

Figure 5. Natural Snake River fall chinook salmon recaptures and recapture intervals, 1991.

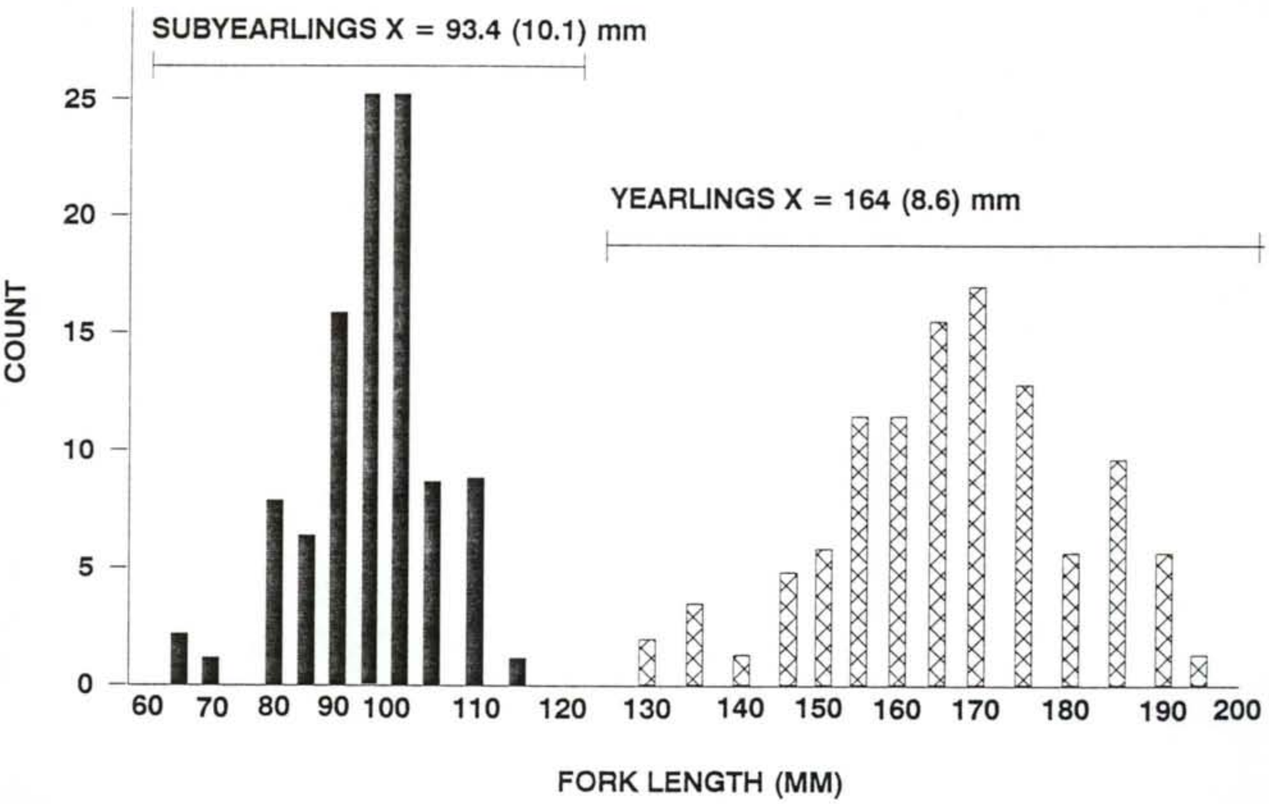

Figure 6. Lyons Ferry Hatchery fall chinook salmon length frequency data, 1990.

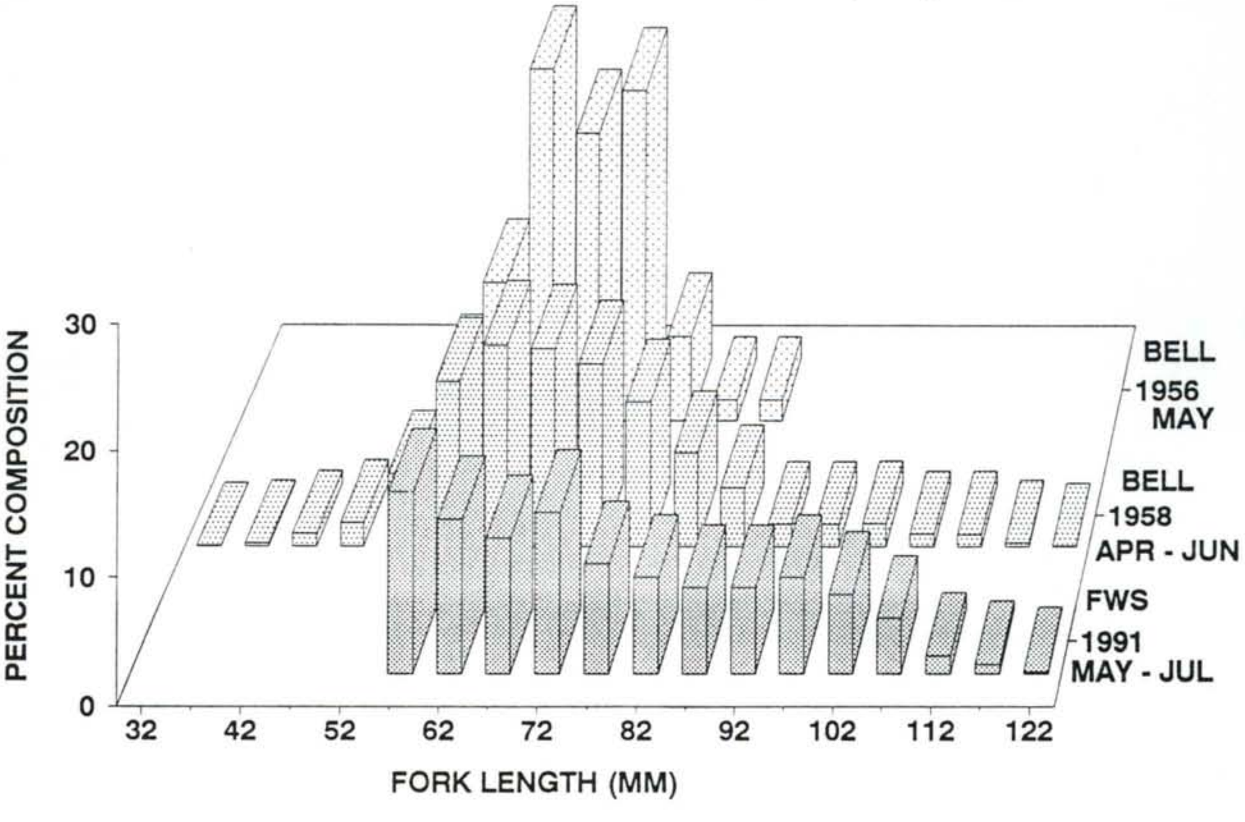

Figure 7. Visual correlation of 1991 natural fall chinook salmon fork length (mm) with literature values, 1956 and 1958.

Emigration

Hatchery salmon.—Yearling and subyearling fall chinook salmon are usually released in the first week of April and the first week of June, respectively. The first passage check point for on-station releases of Lyons Ferry hatchery fall chinook Lower is Monumental Dam (refer to Figure 1). Data compiled by the Fish Passage Center (FPC) in 1990 through gate-well dipping at Lower Monumental indicated that both yearling and subyearling hatchery salmon began arriving at the dam within three days of release. It is difficult to graph the 1990 yearling passage pattern with absolute certainty since no hatchery yearlings were branded. However, FPC data believed to be indicative of Lyons Ferry yearling migration suggests that peak Lower Monumental passage occurred about the third week of April, less than one week after release (Figure 8). Some hatchery subyearling fall chinook salmon from 1989 passed Lower Monumental Dam as yearlings in 1990. Passage of on-station hatchery subyearling releases by Lower Monumental peaked in the third week of June, as in most years (Figure 8). It should be noted that an anomalous July release of 13,000 subyearling salmon was made from Lyons Ferry in 1990.

Natural salmon. We reviewed the 1991 Lower Granite Dam smolt-monitoring program subyearling passage data for a comparison to hatchery emigration (Figure 8). Conclusive race identification of subyearling migrants evaded personnel of the smolt-monitoring program in the past. In most years, subyearling passage data are bimodal. Electrophoretic analyses from the salmon run at large collected in 1991 indicated that the early peak was probably composed of age-0+ spring/summer chinook salmon, while the later peak represented natural fall chinook salmon (Lee Blankenship, WDF, personal communication).

Of the 738 salmon we PIT tagged in the Snake River, 74 were interrogated at Lower Granite Dam. We sacrificed 49 of the 74 salmon for electrophoresis by WDF. A total of 46 of the 49 were fall chinook salmon. The emigration pattern of these known natural fall chinook salmon was protracted (Figure 9), and when we scaled known natural fall chinook data to subyearling data collected by the smolt-monitoring program the similarities were striking (Figure 10). On the basis of this collective analysis, we concluded that Lower Granite passage of natural fall chinook salmon began in June, peaked on July 25, and extended into September when the juvenile bypass and PIT tag interrogation facilities at the dam were shut down.

Additional smolt-monitoring program data presented by FPC for 1985 and 1986 suggest that the outmigration by natural Snake River fall chinook salmon is a summer event and that the 1991 migration was the latest on record (Figure 11).

Discussion

Although our data set consisted of single and separate years, it is evident that Lyons Ferry Hatchery and natural Snake River fall chinook salmon have different emergence, rearing, and outmigration characteristics. These differences can be traced back to water temperature during incubation and behavior during rearing since spawning timing between the two salmon categories is similar.

An in-depth discussion of survivability of hatchery versus natural salmon is well beyond the scope of this paper. However, it cannot be ignored that hatchery fall chinook salmon have the obvious survival benefit of a predator-free rearing environment. The high fidelity to rearing areas we found in naturally produced salmon may compromise survival since these areas are shared with an array of predators.

A more intriguing discussion topic concerns outmigration timing relative to river flow. As a result of thie earlier emergence, Lyons Ferry Hatchery subyearling smolts in 1990 (and most years) were ready for release by early June at the end of the Water Budget (Figure 12). Consequently, subyearling salmon of hatchery origin experience cooler water temperatures and higher flows during migration than their naturally produced subyearling counterparts. Additionally, spill at Lower Monumental is triggered by the arrival of Lyons Ferry brand groups at the dam, so migration rates are further accelerated. Yearling hatchery salmon experienced the highest flow conditions during the 1990 migration (and most years) since they are released from Lyons Ferry at the beginning of the Water Budget (Figure 12). The earlier release date and larger release size of

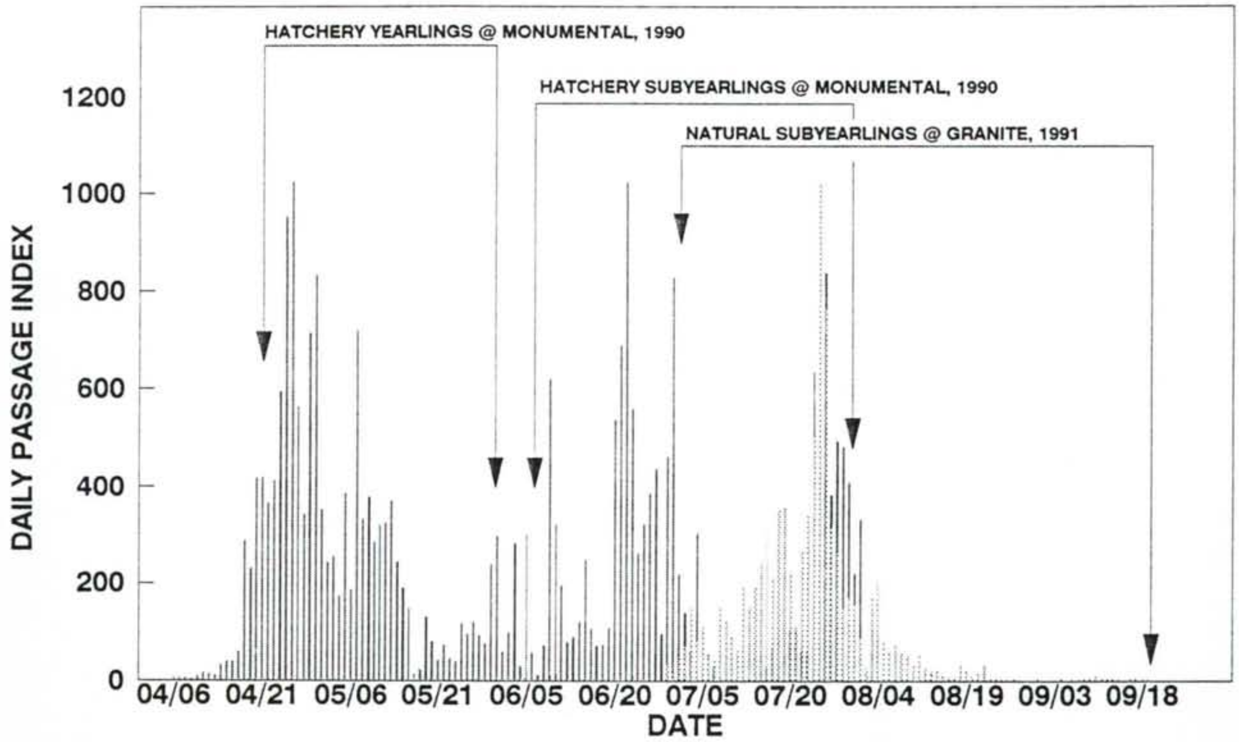

Figure 8. Lower Monumental and Lower Granite Dam passage indices for Lyons Ferry Hatchery and natural Snake River fall chinook salmon, 1990 and 1991 (FPC bi-weekly report data).

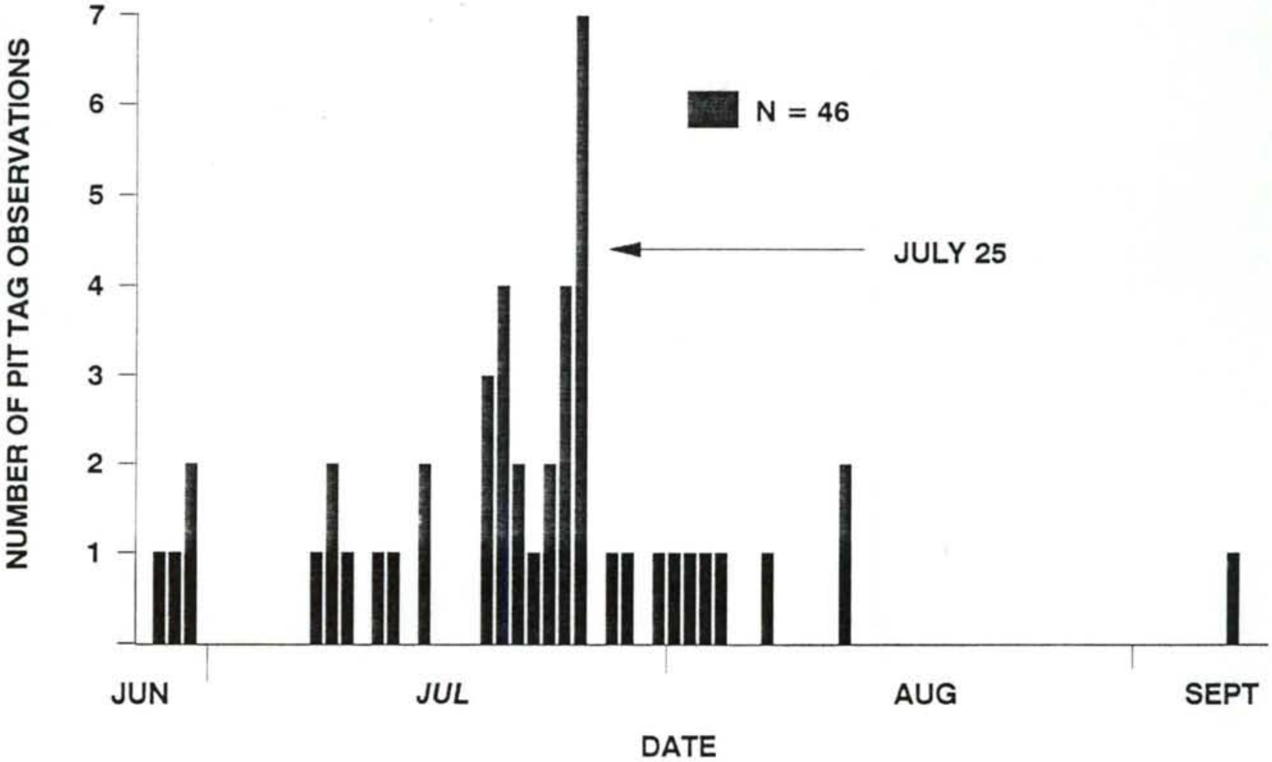

Figure 9. Outmigration timing of PIT tagged natural Snake River Fall chinook salmon Lower Granite Dam, 1991.

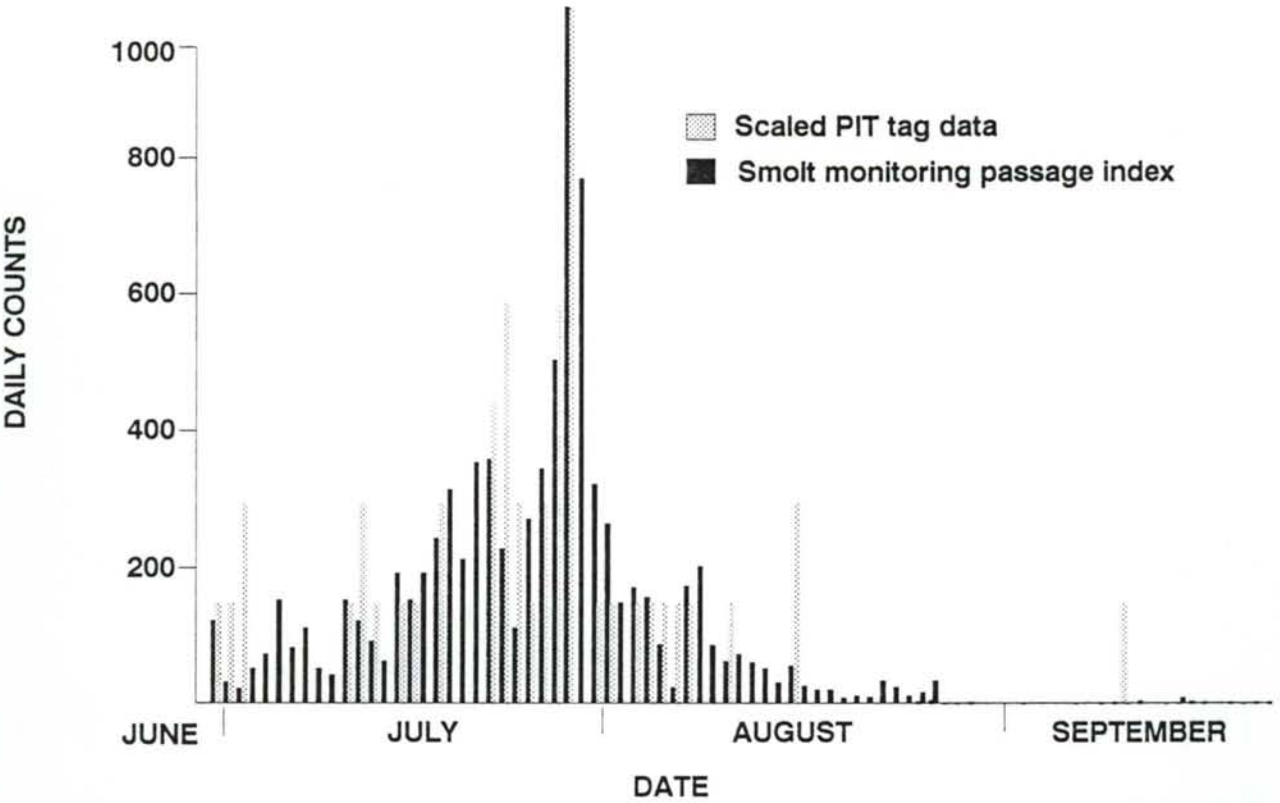

Figure 10. Visual correlation of the subyearling passage index (FPC bi-weekly report data) and PIT tag observation data for known natural fall chinook salmon at Lower Granite Dam, 1991.

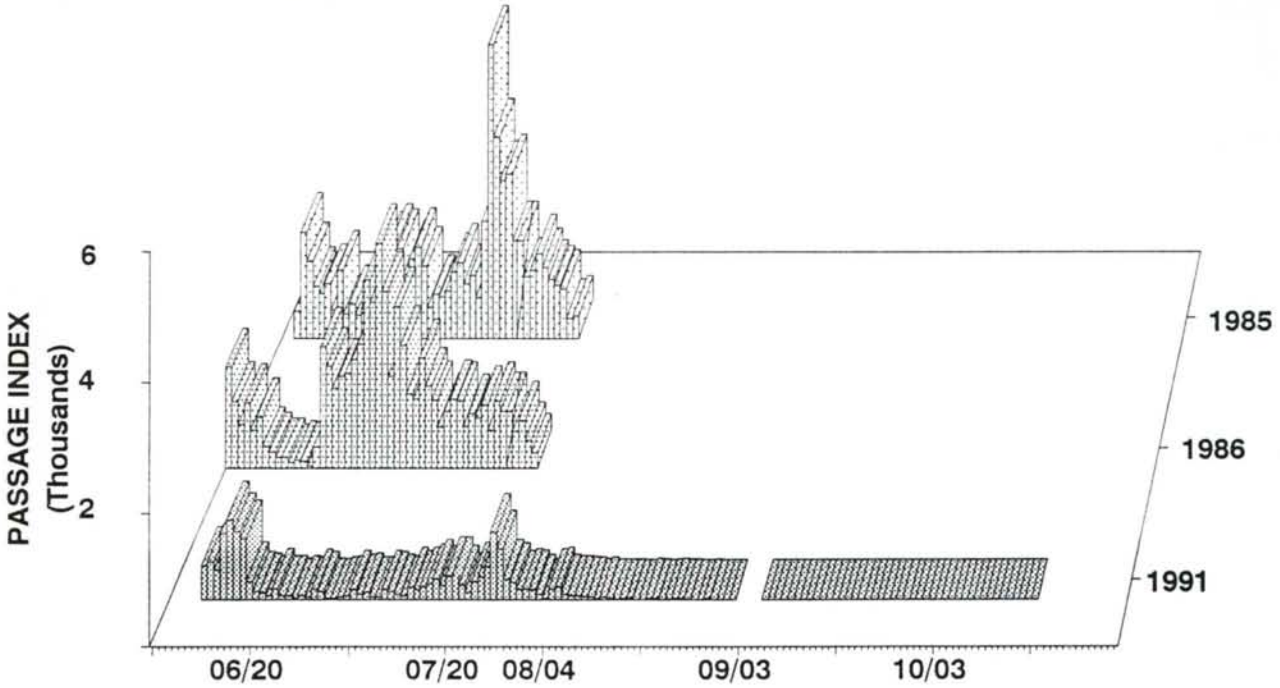

Figure 11. Subyearling passage indices 1985, 1986, and 1991 (FPC bi-weekly report data).

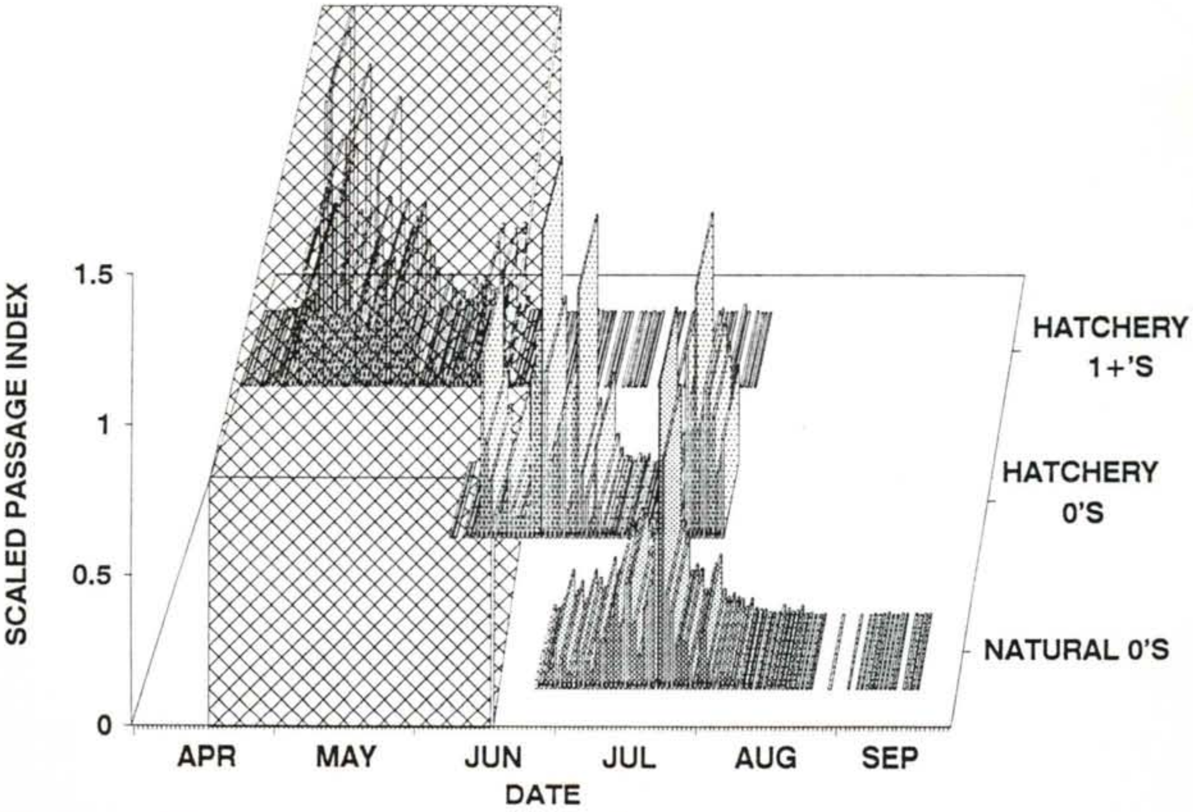

Figure 12. Water Budget coverage for Snake River fall chinook salmon emigration based on 1990 and 1991 passage indices (FPC bi-weekly report data).

yearling hatchery salmon may contribute to the higher smolt to adult return rates for this age class as compared to hatchery subyearling returns. Although this strategy shows promise for hatchery returns, there is no conclusive evidence of yearling outmigration in the natural Snake River fall chinook salmon population.

Perhaps the most important question raised by this brief comparison is whether or not natural fall chinook salmon survival would increase through the amendment of the Water Budget to provide augmented flows in late June and July, since the migration of these fish does not occur during the April 15 to June 15 period of augmented flow provided by the current Water Budget (Figure 12).

Summary

We summarized the most current early life history and outmigration timing data for Lyons Ferry Hatchery and natural Snake River fall chinook salmon. Differences in water temperature between the hatchery and the Snake River influenced the developmental rate of fall chinook eggs, fry, and smolts. We found that (1) hatchery fall chinook eggs hatch earlier than eggs of natural salmon, (2) hatchery fall chinook fry button up earlier than natural fall chinook salmon, (3) hatchery fall chinook salmon are released into the river and smolt earlier than natural fall chinook salmon, (4) the outmigration pattern of hatchery fall chinook is compressed while natural salmon outmigration is protracted, (5) yearling and subyearling hatchery fall chinook are released during Water Budget implementation, while natural salmon outmigrate while summer flows are receding.

Acknowledgments

Lyons Ferry Hatchery is funded through the United States Fish and Wildlife Service Lower Snake Compensation Plan (LSCRP). Natural fall chinook salmon research began in early 1991. It was funded by LSCRP support until mid-1991, when ratepayers of the Bonneville Power Administration assumed the funding role. Numerous employees of the United States Fish and Wildlife Service, Washington Department of Fisheries, University of Idaho, Fish Passage Center, and Washington Department of Wildlife contributed to this presentation. We are particularly grateful for the field assistance of Ralph Bo Roseberg and Mark Pishl.

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Migration Rate/Discharge Relation and Minimum Survival Estimates for Age-1 Chinook Salmon Smolts Migrating through Lower Granite Reservoir, 1987-91

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There is an ongoing controversy in the scientific community about whether the migration rate of chinook salmon smolts *Oncorhynchus tshawytscha* in a reservoir environment is related to flow. Also, some special-interest groups believe that flows greater than 85 kcfs in the Snake River are not beneficial to chinook salmon smolt migration. In this study I examined the relation between migration rate and inflow discharge for chinook salmon smolts migrating through Lower Granite Reservoir within the flow range of 30-120 kcfs during the period 1987-1991. Flows did not exceed 120 kcfs during this period. I also examined the minimum survival estimate for chinook salmon smolts released from the Snake River or Clearwater River traps.

Methods

Chinook salmon smolts were collected, PIT (Passive Integrated Transponder) tagged, and released daily (150 smolts) at the Snake River trap and the Clearwater River trap, located at Lewiston, Idaho (Buettner 1991). These fish were subsequently interrogated at either Lower Granite, Little Goose, or McNary dams. Median travel time to Lower Granite Dam was calculated for each daily release group and mean inflow discharge was calculated for the median travel time interval. Travel time was then converted to migration rate to standardize the distance to Lower Granite dam from the two trap sites. The data were stratified by 5-kcfs discharge intervals (Mosteller and Tukey 1977) and log (ln) transformed (Zar 1984). The linear regression model (Ott 1977) was used to describe the relation between chinook salmon smolt migration rate and inflow discharge. An analysis of covariance (Ott 1977) was used to determine if there was a difference in migration rate/discharge relations among years.

Minimum survival estimates (yearly interrogation rate at Lower Granite, Little Goose, and McNary dams, combined) were calculated for smolts released from the Snake River trap and the Clearwater River trap. The data were compared over years 1987-1991 and between tagging locations.

Results and Discussion

Migration Rate/Discharge Relation

In 1991, 25 daily release groups were stratified by 5-kcfs discharge intervals into 14 stratified groups at the Snake River trap. Linear regression analysis indicated that as discharge increased, migration rate also increased. Chinook salmon migration rate was 3.0 km/d at a discharge of 30 kcfs and 12.6 km/d at 100 kcfs (Figure 1). Discharge accounted for 88.5% of the variation in migration rate ($r^2 = 0.821$, $N = 14$, $P < 0.001$):

$$\ln(\text{migration rate}) = -3.015 + 1.215 \ln(\text{mean discharge}).$$

Migration rate/discharge data from the Snake River trap to Lower Granite dam is available for 1987-1991 (Figure 2). In each year, as discharge increased, migration rate also increased. In all years the correlation coefficient (r^2) is greater than 0.800. In three of the five years it is above 0.940, indicating the strong relation between migration rate and discharge over the entire range of discharge and over time (Table 1).

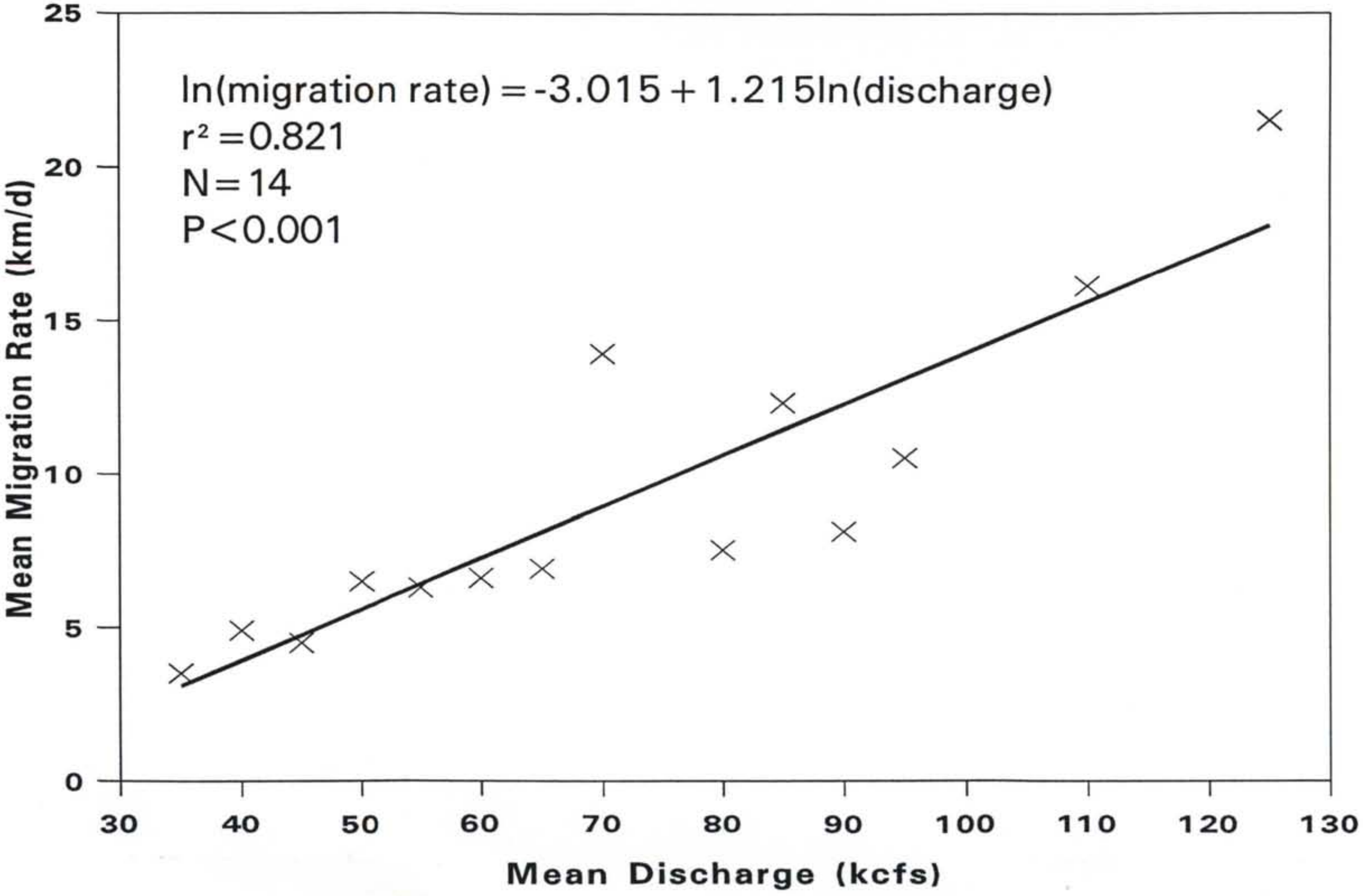

Figure 1. Migration rate/discharge relation through Lower Granite Reservoir for chinook salmon PIT tagged at the Snake River trap, 1991.

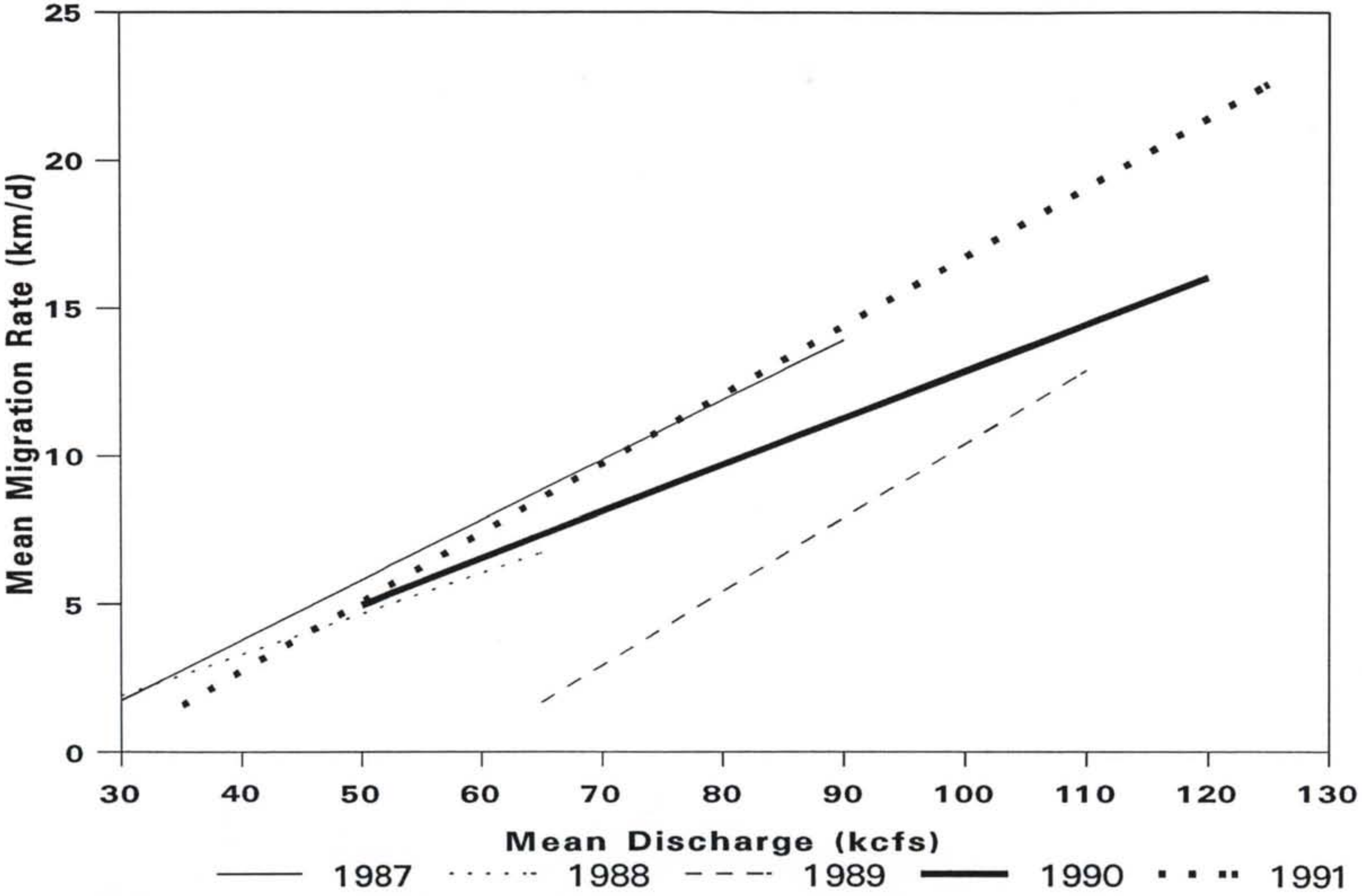

Figure 2. Migration rate/discharge relations through Lower Granite Reservoir for chinook salmon PIT tagged at the Snake River trap, 1987-1991.

TABLE 1.—Linear regression analysis of migration rate/discharge relation for chinook salmon PIT tagged at the Snake River trap and interrogated at Lower Granite Dam, 1987-1991.

Year	sample size (N)	r^2	*P*
1991	13	0.885	<0.001
1990	10	0.806	<0.001
1989	10	0.951	:50.001
1988	7	0.943	<0.001
1987	8	0.946	<0.001

TABLE 2.—Chinook salmon minimum survival estimate (interrogation at Lower Granite, Little Goose, or McNary dams), to Lower Granite Dam for fish PIT tagged at the Snake and Clearwater River traps, 1988-1991.

Year	Snake River (%)	Clearwater River (%)
1991	68.2	60.5
1990	64.4	54.6
1989	68.0	55.2
1988	55.2	

The chinook salmon migration rate/discharge relation for the Snake River trap PIT tag groups was examined to determine a difference in the relation among years 1987-1991. An analysis of covariance of the stratified (5-kcfs intervals) data showed a significant difference in the migration rate/discharge relation among years (F = 12.212, N = 48, $P < 0.001$). The 1989 data had a slightly steeper slope (Figure 2). Without the 1989 data a significant difference in the slopes of the remaining four years of data could not be detected (F = 1.887, N = 38, $P = 0.153$). The analysis of covariance was continued to test for a difference in the Y-intercepts (height) of the lines for the four years of data. Again no difference could be detected (F = 2.398, N = 38, $P = 0.086$), indicating a common migration rate/discharge relation for 1987, 1988, 1990, and 1991.

In all years except 1989, migration rate increased twofold between 60-100 kcfs. Migration rate increased about threefold from 60 to 100 kcfs in 1989. All five years' data showed the same basic relation: as flow increases, migration rate increases. The amount of increase differed slightly in 1989, but the trend remains constant. The slight curvilinear nature of the data indicates that discharge has more of an effect on migration rate at flows greater than 100 kcfs than at lower flows.

Migration rate/discharge data is available at the Clearwater River trap for 1990-1991 (Figure 3). These data display similar and significant relations between discharge and migration rate.

Lower Granite Dam Chinook Salmon Minimum Survival Estimate

The proportion of chinook salmon PIT tagged at the Snake or Clearwater River traps and subsequently interrogated at Lower Granite, Little Goose, or McNary dams is termed the Lower Granite Dam minimum survival estimate:

$$\frac{\textit{Number PIT Tags Interrogated}}{\textit{Total Number PIT Tagged}} \times 100$$

If these fish were interrogated at one of these three facilities they had to have been alive when they passed Lower Granite Dam. Those fish not contributing to the minimum survival estimate consist of reservoir mortality, dam mortality, fish that residualized and did not migrate, and fish that passed out of the system without being interrogated. The portion that migrate out of the system without being interrogated is probably very small, less than 5%.

Annual chinook salmon minimum survival estimates to Lower Granite Dam for 1988-1991 ranged from 55% to 68% for fish tagged at the Snake River trap and from 54% to 60% for fish tagged at the Clearwater River trap in 1989-1991 (Table 2). For 1989-1991 the minimum survival estimates were consistently higher for chinook salmon PIT tagged at the Snake River trap. The reason for the difference is unclear. Two factors that may contribute to the difference are that fish migrating out of the Clearwater River at flows greater than 35 kcfs were not captured and therefore not PIT tagged. Smolts migrating under better Clearwater River flow conditions may have shown better overall minimum survival. Secondly, large numbers of the fish PIT tagged at the Clearwater River trap were released from Dworshak National Fish Hatchery, 55.2 km upstream of the trap. The closest hatchery release to the Snake River trap is at Hells Canyon Dam, 173 km upstream. More hatchery fish may have died before they reached the Snake River trap because of longer travel distances and time. Because of the close proximity of Dworshak to the Clearwater River trap, weak fish released from Dworshak may not have died until after they reached the trap. This explanation is unsatisfactory, however, because we also found that the minimum survival estimate for wild steelhead *Oncorhynchus mykiss* was higher for those PIT tagged at the Snake River trap (Buettner 1991).

The minimum survival estimate for 1987 was biased because only chinook salmon in good condition were PIT tagged. Despite this bias the minimum survival estimate for that year was the poorest of the five years sampled (1987 minimum survival estimate = 52.3%). This year was the poorest water year of the drought years (1987- 1991). Without the bias the minimum survival estimate would undoubtedly have been lower.

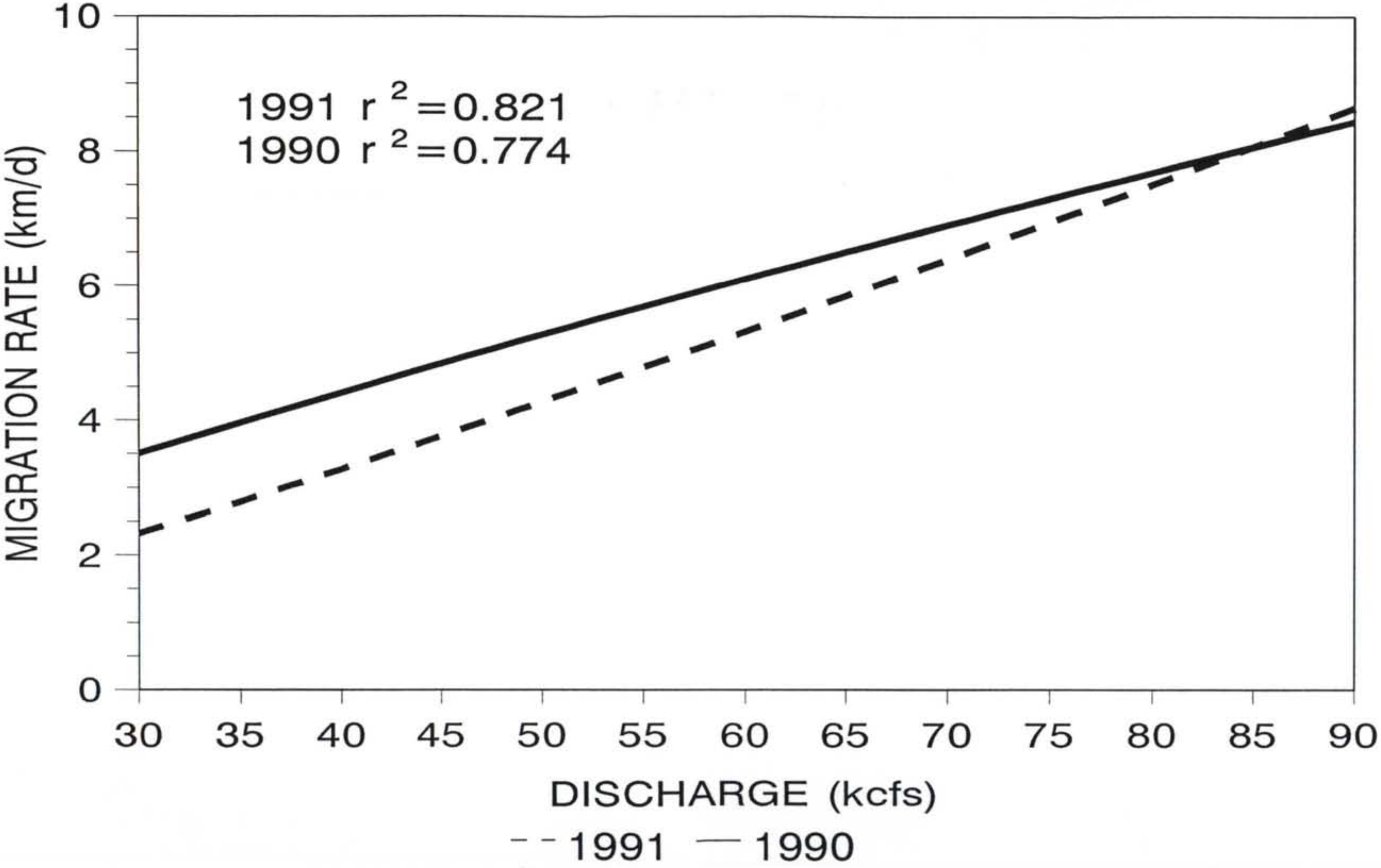

Figure 3. Migration rate/discharge relations through Lower Granite Reservoir for chinook salmon PIT tagged at the Clearwater River trap, 1990-1991.

Summary

1. There was a strong positive correlation between migration rate of chinook salmon smolts and inflow discharge between the Snake River trap and Lower Granite Dam, 1988-1991, and between the Clearwater River trap and Lower Granite Dam, 1990-1991.

2. The strong relation between migration rate and discharge existed over the range of discharge observed (30-125 kcfs) and was consistent each year of the study.

3. A significant difference was not detected in the migration rate/discharge relation among four of the five years' data. All five years' data exhibited the same basic relation: an increased migration rate is associated with increased flow. The 1989 Snake River trap data exhibited a slightly steeper slope.

4. Chinook salmon minimum survival estimates to Lower Granite Dam ranged from 54 to 68% at the two traps.

5. The minimum survival estimate for chinook salmon PIT tagged at the Clearwater River was consistently lower than for fish from the Snake River trap.

6. The "bottom line": The higher the discharge during the spring outmigration, the faster fish will migrate. Chinook salmon migration rate continues to increase as flows exceed 85 kcfs.

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Predation on Juvenile Salmonids by Northern Squawfish in Columbia and Snake River Reservoirs

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Introduction

Predation by resident fishes has long been a suspected source of juvenile salmonid mortality in Columbia and Snake River reservoirs (Uremovich et al. 1980). The principal predators in the Columbia River basin are northern squawfish *Ptychocheilus oregonensis*, walleye *Stizostedion vitreum vitreum*, smallmouth bass *Micropterus dolomieu*, and channel catfish *Ictalurus punctatus* (Hjort et al. 1981). Northern squawfish have been shown to be responsible for most of the loss of juvenile salmonids to predation in John Day Reservoir (Rieman et al. 1991).

The objective of this paper is to address four questions about predation on juvenile salmonids by northern squawfish in Columbia and Snake River reservoirs:

1. What is the history of the predation problem in the Columbia River basin and what do we currently know about predation?

2. Given what we know about predation, what are the outstanding problems that remain to be solved and what is their relative importance?

3. How would proposed changes in river management potentially affect predation and current efforts to manage predation?

4. What are the priorities for future research and management given the outstanding problems and the anticipated responses of predation to proposed changes in river management?

History

Northern squawfish have long been recognized as predators on other fish. Clemens and Munro (1934) found that of 119 northern squawfish from various British Columbia lakes examined, 67 had eaten fish, and 27 of these had eaten juvenile salmonids. Ricker (1941) also reported that northern squawfish consume juvenile salmonids. Foerster and Ricker (1941) found that the survival rate of juvenile salmonids in Cultus Lake, British Columbia, increased after northern squawfish numbers were reduced.

After dams were constructed in the Columbia River basin, biologists soon realized that large numbers of juvenile salmonids were being lost to predation by northern squawfish. Zimmer (1953) reported that extensive predation occurred within Bonneville Reservoir near the Little White Salmon River. The U.S. Fish and Wildlife Service (USFWS 1957) reported that northern squawfish were attracted by releases of young salmon from hatcheries, and Thompson (1959) detected localized predation on hatchery-released salmon. Other studies have shown northern squawfish to be abundant in tailraces immediately downstream from dams (Sims et al. 1978), and in forebays immediately upstream from dams (Uremovich et al. 1980).

The detection of the potential for predation by northern squawfish prompted fisheries agencies to form the Predator-Prey Research Committee in 1980. This committee defined the information needs underlying a Predator-Prey Study conducted by the Oregon Department of Fish and Wildlife (ODFW) and USFWS in John Day Reservoir from 1983 through 1986. The major findings from this study were that (1) northern squawfish were the most abundant and widely distributed predator in John Day Reservoir (Beamesderfer and Rieman 1991), (2) juvenile salmonids were the most important food group by weight of northern squawfish (Poe et al. 1991; Vigg et al. 1991), and (3) northern squawfish were responsible for 78% of the mean annual loss to predation of 2.7 million juvenile salmonids in the reservoir (Rieman et al. 1991). Additionally, modelling by Rieman and Beamesderfer (1990) showed that reductions in northern squawfish predation of up to 50% may be possible with limited (10-20%) but sustained exploitation of northern squawfish longer than 275 mm fork length.

A program to manage predation at federal projects in the Columbia River basin (Nigro 1990; Poe 1992; Willis and Nigro 1992) is based on the concept of sustained exploitation described by Rieman and Beamesderfer (1990). Primary objectives of the program are to (1) determine the significance of predation by northern squawfish in Columbia River basin reservoirs by indexing northern squawfish abundance and consumption; (2) implement fisheries for northern squawfish in the Columbia River basin reservoirs; (3) evaluate the effectiveness of fisheries in reducing northern squawfish numbers, altering northern squawfish population structure, and reducing predation on juvenile salmonids; (4) develop and test promising new methods to harvest northern squawfish; and (5) develop and test the effectiveness of prey protection measures in reducing predation. Fisheries being implemented include (1) agency personnel angling from dams, (2) a public sport-reward fishery, and (3) a commercial longline fishery. New methods being tested include trolling lures, using Merwin Traps, purse seining, and electrofishing.

The current effort to remove 10-20% of the northern squawfish from Columbia and Snake River reservoirs is not the first attempt to reduce northern squawfish numbers. In the past, fish and wildlife agencies have attempted to remove northern squawfish by a variety of methods, including electrofishing (Maxfield et al. 1959), netting and seining (Foerster and Ricker 1941; Zimmer 1953), dynamite (Jeppson 1957), poison (Keating 1958), and water level manipulation (Jeppson 1957). These programs failed in part because only localized removals were attempted and no plans were made to sustain efforts.

Outstanding Problems

Many outstanding problems related to predation in the Columbia River basin remain to be solved. Most of these are addressed by the current program to manage predation. The most important outstanding problems are:

1. What is the significance of predator-caused mortality system-wide? We are using a predation index to describe the relative magnitude of predator-caused mortality in various reservoirs, and to identify areas within reservoirs with high levels of predation.

2. What are the dynamics of predator-caused mortality? We are conducting studies to describe the relationships among predation, physical parameters, and biological parameters. We are determining the extent to which predation mortality may explain unaccounted losses of juvenile salmonids.

3. What is the extent of predator-caused mortality on healthy juvenile salmonids? We are conducting studies to determine whether northern squawfish preferentially select unhealthy or injured juvenile salmonids.

4. What is the feasibility of obtaining approval to use squoxin to reduce northern squawfish abundance? Others have reviewed existing data and identified the studies needed to evaluate the adequacy of squoxin to selectively remove northern squawfish, and to gain approval by EPA for its use in public waters.

5. Can predator abundance be controlled by altering predator spawning and nursery habitat or by localized use of toxicants? We are conducting studies to locate and describe habitat used by northern squawfish for spawning and rearing, and to describe the reproductive behavior of northern squawfish.

6. How do northern squawfish populations respond to reductions in abundance? We are conducting studies to estimate the rate at which northern squawfish repopulate areas and to determine whether the consumption rate and reproductive potential of surviving fish change.

7. Can predator-prey encounters and predator feeding efficiencies be reduced? We are conducting studies to determine the daily feeding chronology and swimming ability of northern squawfish, and to determine whether predator alarm substances affect predation rates.

8. What is the feasibility of developing bounty, commercial, or hook-and-line fisheries for northern squawfish? We are conducting studies to determine the magnitude of the fisheries needed to reduce northern squawfish populations 10-20%, and to determine the potential for developing markets for northern squawfish.

9. How cost-effective are measures to reduce the predator-caused mortality of juvenile salmonids? We are conducting studies to estimate the costs of implementing various methods to reduce juvenile salmonid mortality, and to compare these to the costs of predation control measures.

10. What is the response of other resident fishes to the implementation of various predation control measures? We are conducting studies to estimate changes in the abundance and dynamics of resident fishes, and in the consumption of juvenile salmonids by predatory fish other than northern squawfish.

Effects of Proposed Changes

For the purposes of this paper, proposed changes in river management fall into two categories: (1) changes in predation management, and (2) all other management changes. Predation management may be further partitioned into techniques for removing predators, and techniques for protecing prey. Predator removal (outstanding problems 4, 5, and 8) is designed to have a direct effect on predator abundance, and therefore an indirect effect on the survival of juvenile salmonids and ultimately on returns of adult salmonids. Prey protection measures are designed to minimize predator and prey interactions (outstanding problem 7) and include efforts to locate juvenile salmonid bypass outfalls and hatchery release sites in areas and under conditions that minimize predation losses.

Other river management changes include manipulating flow or spill. These options may affect predation by reducing the residence time and thus the exposure to predators of juvenile salmonids in reservoirs. The potential effects of these management options are being evaluated by the use of models such as the Columbia River Ecosystem Model (CREM) and the Columbia River Salmon Passage Model (CRISP).

Future Priorities

The priority for future research is to address the outstanding problems of predation, many of which are already being addressed by current research. ODFW and the USFWS are conducting research to determine the significance of predation throughout the Columbia River basin, the dynamics of predation, the extent of predation on healthy and unhealthy juvenile salmonids, the response of northern squawfish populations to reductions, the effect of prey protection measures, and the response of other resident fishes to the implementation of control measures. Various agencies are involved in determining the feasibility of developing fisheries for northern squawfish.

The priority for future management is to reduce predation-caused mortality to juvenile salmonids. Ongoing research should provide managers with the necessary tools to realize this goal.

Summary

1. Northern squawfish have long been recognized as predators on other fish, especially since dams have been constructed in the Columbia River basin.

2. Research in John Day Reservoir indicated that northern squawfish were responsible for 78% of the mean annual loss to predation of 2.7 million juvenile salmonids. Modelling indicated that reductions in northern squawfish predation of up to 50% are possible with limited (10-20%) but sustained exploitation of northern squawfish.

3. The primary objectives of the current program to manage predation are to determine the significance of predation by northern squawfish throughout the Columbia River basin, implement fisheries for northern squawfish, evaluate the effectiveness of the fisheries, and develop and test new methods to remove northern squawfish.

4. Many outstanding problems related to predation remain. Most of them are being addressed addressed by studies within the current program to manage predation in the Columbia River basin.

5. Changes in river management other than predator control, such as manipulation of flow or spill, may affect predation by reducing the residence time and thus the exposure to predators of juvenile salmonids in reservoirs. These effects are being evaluated by the use of models.

6. The priority for future research is to address the remaining outstanding problems. The priority for future management is to use the tools provided by research to reduce predation-caused mortality.

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Gas Supersaturation: Historical Perspective and Future Prospects

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Introduction

Spillage at dams is known to be a point source of gas supersaturation, and information on this subject comprises a voluminous literature both across the nation and around the world. Judging from the reaction of engineers to this phenomenon, the supersaturation problem was not expected in the Columbia River Basin when the dams were designed. Consequently, the cause-effect relationship was doubted for some time and the reality was accepted only after protracted periods of research. Most of the early concern and investigations were based on dead adult salmon, perhaps because their carcasses are large and easily noticed. While supersaturation also impacts smolts and small fishes, these are rarely found dead in a river, even during fish kills. Therefore, we will address the reservoir drawdown issue from several perspectives, considering both adults and smolts, historical background, gas supersaturation standards, etiological considerations in gas bubble disease, and tolerance of smolts. We will then describe the physical factors of dams relating to gas supersaturation in possible drawdown scenarios, and describe a gas supersaturation kill of adult salmon at John Day Dam as a potentially similar scenario.

Historical Background

Bonneville Dam was one of the first dams constructed on the Columbia River and is located nearly 150 miles from the Pacific Ocean. The discharge of the Columbia River commonly exceeds 7,000 cubic meters per second (cms), which easily qualifies it as a large river. Soon after Bonneville Dam closed in 1938, dead adult salmon were observed below it by fishermen (Merrill et al. 1971).

By 1943, the Washington Department of Fisheries was sufficiently concerned that it began an investigation of the cause-effect relationship (Merrill et al. 1971). In 1946, a formal investigation was begun by the U.S. Fish and Wildlife Service and the U.S. Army Corps of Engineers into the significance and cause of death of the observed dead adult salmon (Hanson et al. 1950). Later, *The Oregonian* took up the issue and reported on June 12, 1952, that a commercial fisherman had found "thousands" of dead adult chinook between Bonneville Dam and the Lewis River.

Mortality estimates below Bonneville Dam were begun in 1954 by Merrill et al. (1971), using marked adult male chinook salmon carcasses derived from hatcheries. After being dumped into the river, only 2.65% of the 1169 tagged adult chinook carcasses were recovered, and on that basis, Merrill (1971) estimated that at least 16.7% of the spring/summer chinook run had been killed. No estimate of mortality was attempted for smolts.

Although the supersaturation cause-effect relationship was still not clear, Merrill et al. associated the problem with flows at or exceeding 7,000 cubic meters per second (cms) or about 247,000 cubic feet per second (cfs). Flows this large occurred annually from 1946 through 1955, and were generally highest during the summer chinook run which Merrill et al. (1971) believed was being impacted the worst. Later, Westgard (1964) reported gas bubble disease among spring chinook in the McNary spawning channel and suspected that the supersaturated gases came from spillage at dams. By the late 1960s, Ebel (1969) and his coworkers had clearly proven that spillage at Columbia River dams was the cause of the air-supersaturated water and that this resulted in gas bubble disease.

Spillage at Columbia River dams occurred for two historical reasons. Most mainstem dams closed before their powerhouse was ready to function, so it was necessary for them to spill most of the river. Secondly, when a powerhouse became functional, spillage occurred whenever runoff flows exceeded powerhouse capacity. For example, significant gas supersaturation probably occurred in the lower Columbia River whenever flows exceeded 7,000 cms. This is because the powerhouse capacity of Bonneville Dam was only about 4,000 cms and it was common for flows to reach 14,000 cms annually. Only once has an accident in a powerhouse (at John Day Dam) caused the total river to be spilled, and this also resulted in dangerous levels of air supersaturation.

By the mid or late 1970s, the supersaturation problem was assumed to be ended below mainstem dams, first by spillway modifications, and later by the elimination of spill. Spill was reinstituted to promote smolt passage via a "water budget" by the Northwest Power Planning Council. With the return to spill, there was a return to supersaturation, and dissolved gas levels generally exceed 110% percent and often exceed 120% in the Columbia and Snake rivers (personal communication, William Sobolewski, Environmental Protection Agency, Portland, Oregon).

Gas Supersaturation Water Quality Standard

The maximum allowable level for gas supersaturation was recommended at 110% by the National Academy of Science (EPA 1972). Subsequently, the NAS recommendation was adopted as a water quality criterion by the Environmental Protection Agency (EPA), and later this level was adopted as a water quality standard in Oregon and Washington. This standard is conservative, and indicates a concern for safety relative to unknown interactions and possible future events.

The water quality standard drops to only 105% in Oregon rivers if aquaculture is involved. This provision is intended to protect all potential beneficial usages of the water, such as the rearing of fish in floating netpens.

There is ample evidence to indicate that a standard of 105% is not adequate to protect sensitive life stages of fish in the confines of a hatchery. Conversely, there is considerable evidence that the lethal level of supersaturation for feral or wild smolts is above 115%. Thus, controversy exists over how much supersaturation should be allowed for salmon in various circumstances, or for resident fish and their ecosystem.

Enforcement of the gas supersaturation standard has been impossible, mainly due to decisions that rendered it moot. That is, after the EPA adopted the supersaturation standard, it determined that under Section 402(a) of the Clean Water Act, dam-caused pollution was not a point-source under Section 502(12), and that air supersaturation was not a pollutant under Section 502(6). In subsequent litigation (National Wildlife Federation vs. Gorsuch), the EPA argued that dam-induced supersaturation did not constitute the "discharge of a pollutant" as defined in Section 512 of the act, and that supersaturation should be regulated under state-developed waste treatment management plans pursuant to Section 208 of the act. EPA's position was supported by the appeals court which believed that EPA's interpretation was entitled to great deference.

Any enforcement of the State's water quality standard for supersaturation will apparently require definition of dams as point sources of gas supersaturation, definition of supersaturation as "pollution," or both. Additional changes may be needed, since most of the dams are federally owned and operated, and therefore would not be subject to control by state/agencies.

Etiology of Gas Bubble Disease

Several excellent literature reviews on gas bubble disease are available, e.g., Harvey (1975) and Weitkamp and Katz (1980). Early studies of gas bubble disease can be traced back to Robert Boyle (1670). Although often ascribed to nitrogen alone, gas bubble disease is the result of the collective uncompensated dissolved gas pressures, and not of nitrogen gas alone (Allee, 1913; Doudoroff, 1957; Harvey 1975; Bouck 1980). The nitrogen component does increase the intensity, and hence the speed, of the syndrome. Bubbles that form in the blood and tissues have gas compositions similar to those in the water. There is speculation that carbon dioxide provides the first microbubble in vivo, after which all dissolved gases enter the bubble until each gas in the bubble is in a pressure equilibrium with its dissolved phase.

Hydrostatic pressure can compensate the gas pressure in bubbles and preclude their growth. However, this assumes that fish behavior will protect fish by keeping them at sufficient depth to maintain a water pressure equal to or greater than the total gas pressure. Fish can be deprived of the compensatory water pressure by the shallow depth in fishways, and may reach zero or negative atmospheric pressure (vacuum) while passing through a turbine.

Tolerance of Smolts

A great deal of research has been published on the tolerance of salmon smolts to gas supersaturation in laboratory conditions (see previous reviews).

Undoubtedly, most feral smolts can tolerate the direct effects of "moderate" supersaturation, under undisturbed riverine conditions. But dams disrupt this migration, forcing smolts into turbine bays, smolt bypass systems, or spillways, each with its own stresses. In these cases, the impact of supersaturation on survival is compounded by the need to avoid predators, or possibly to resist diseases. For example, when passing downward through a turbine bay, a fish encounters a vacuum underneath the turbine blade, which at times can be sufficient to erode and pit steel. Assuming a smolt avoids areas of cavitation and is not struck by the slow moving runner (blade), there is a sudden loss of hydrostatic pressure in combination with turbulence and supersaturated blood gases. We speculate that this is life threatening because the sudden pressure loss can cause emboli in the blood and lateral line system. The result is likely to leave the smolt disoriented and debilitated, with a much reduced potential for avoiding predators that concentrate below dams.

Factors Relating to Gas Supersaturation in Drawdown of Snake River Reservoirs

In 1991, the Idaho Department of Fish and Game and other concerned groups proposed that reservoirs in the lower Snake River be drafted 20-28 feet (6.1-8.5 m) during the smolt migration. Additionally, the majority of the river flow would be passed over the spillway during this period.

These conditions were hypothesized to increase the survival of smolts by reducing travel time and turbine-related mortality. Subsequently, the U.S. Army Corps of Engineers (COE) agreed to test this scenario in March, 1992, and examine various physical and structural factors that might be affected. Here we review the physical factors that cause gas supersaturation and provide some perspective on the levels of gas supersaturation that might result under the proposed conditions.

The main cause of supersaturation in the Snake and Columbia Rivers is the spillage of water at dams. Air and water are mixed when water is spilled and plunged to various depths. The level of supersaturation depends on the depth (pressure) this mixture experiences; thus, the depth of the stilling basin and the volume of water spilled (Figure 1) are important factors. Theoretically, 200% saturation can be reached if the stilling basin is 34 feet (10 m) deep, which is equivalent to one atmosphere of hydrostatic pressure.

Levels ranging from 130 to 138% were commonly reached in the Snake River throughout the entire spring migration period from mid-April to July in the late 1960s and early 1970s (Figure 2). These high levels of

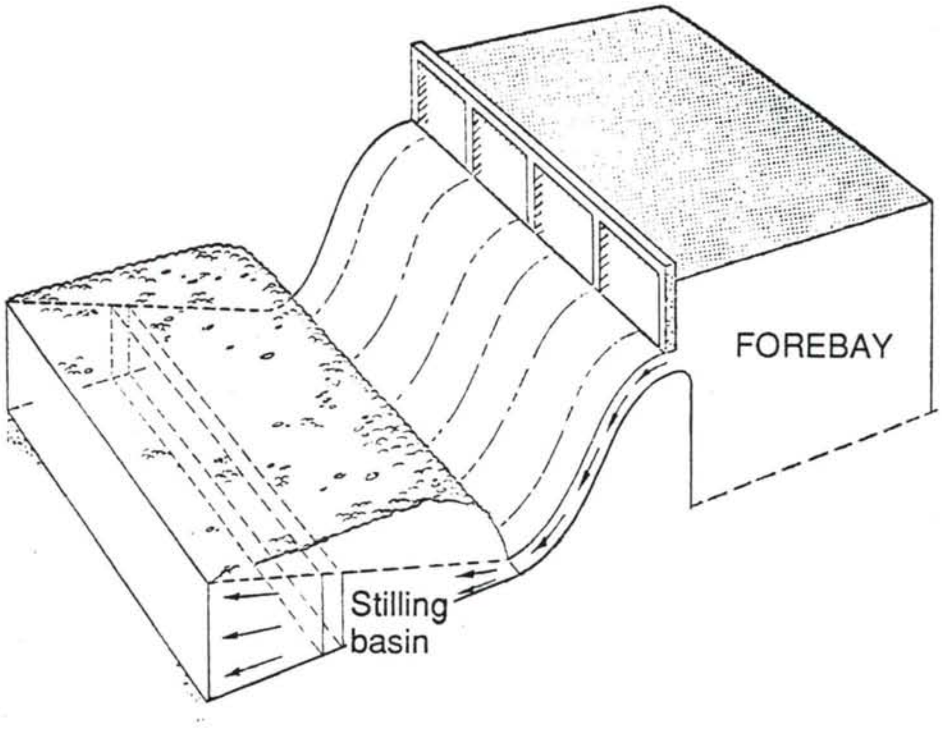

Figure 1. Typical spillway and stilling basin combination used in the Columbia and Snake Rivers.

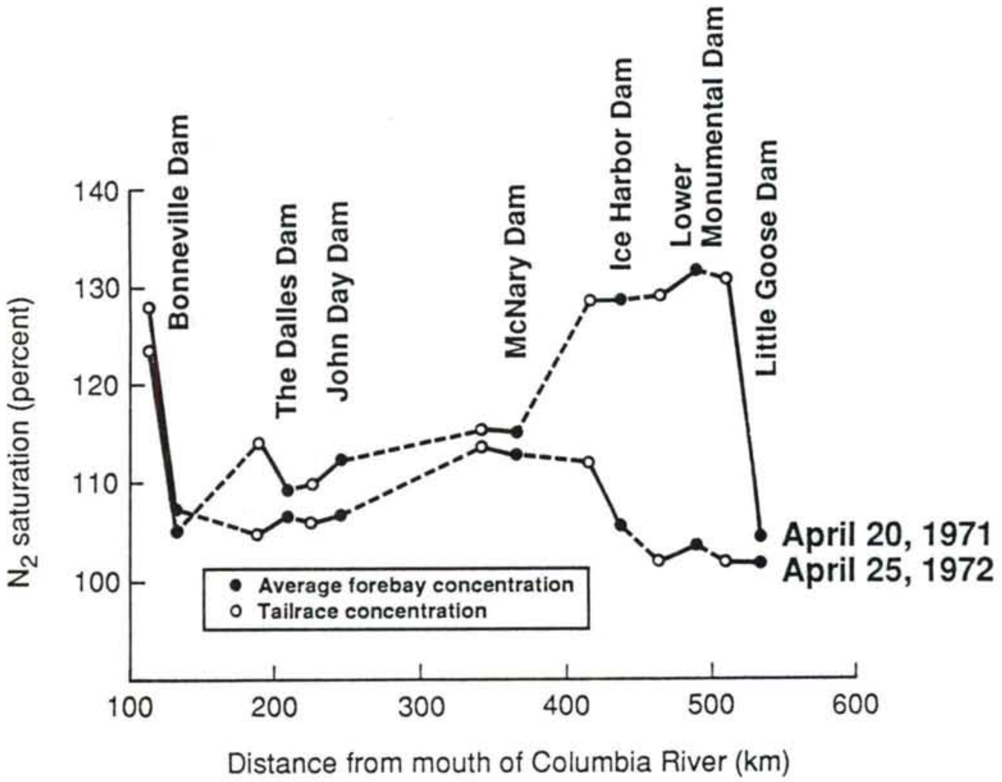

Figure 2. Forebay and tailrace saturation levels of nitrogen in the Snake and Columbia rivers in April 1971 and 1972.

supersaturation occurred because large volumes of water were spilled. The maximum turbine capacity at the time was about 60,000 cfs when three turbines were in operation. The uppermost dam usually had only one turbine in operation. Therefore, even during low to average flow years, large volumes of water were spilled.

Spillway deflectors (Figure 3) were installed and in operation by the mid-1970s to reduce the depth that the air and water mixture would plunge. Concurrently, additional turbines were installed, which substantially reduced the volume of water spilled. Thus, by 1980, the problem was solved as long as a sufficient volume of river flow passed through the turbines to maintain the effectiveness of the spillway deflectors.

Under the proposed drawdown conditions for 1992, various combinations of spillway and turbine flow will be tested. The effectiveness of the spillway deflectors at various flows is therefore an important consideration in determining the level of supersaturation that might occur. The rating curves for the deflectors on the Snake River Dams show that they are effective up to about 50-60,000 cfs at Little Goose Dam (Figure 4). Flows above 60,000 cfs produce levels exceeding 125%. Deflectors are more effective at Lower Granite and Lower Monumental dams, where gas levels would not be expected to exceed 125% even at 150,000 cfs.

The rating curves were obtained from data collected when reservoir and tailwater elevations were near maximum. Gas levels that might result under the proposed drawdown conditions could be substantially higher because the effectiveness of the deflectors would be significantly reduced. Model studies conducted by the COE show that lower tailwater elevations cause the spilled water to plunge and not deflect. Thus, spillage into lower tailwater would probably result in higher levels of gas supersaturation than predicted by these rating curves.

Utilizing the rating curves for the spillway deflectors and calculating weighted averages for spill and turbine flow for each tail race, concentrations of dissolved atmospheric gas can be estimated for the river stretches downstream from Lower Granite Dam at various river discharges. For example, at a discharge of 100,000 cfs and if all the water is being spilled, gas levels exceeding 120% are likely to occur downstream from Lower Granite Dam and exceeding 125% downstream from Little Goose Dam. If 50% of the flow is passed through turbines, the gas levels will probably not exceed 110% between Lower Granite and Little Goose Dams and probably would not exceed 120% downstream from Little Goose Dam.

The above estimates assume that water arriving at Lower Granite Dam is near equilibration (100%) with atmospheric gases and that reservoir elevations are at normal operating levels. Although these estimates cannot be considered precise, they do illustrate the importance of passing a portion of the flow through the turbines. Saturation levels for various other scenarios can be estimated to provide a perspective on what levels might be expected under normal operating conditions. Under the drawdown conditions proposed, substantially higher gas levels would occur. The saturation levels recorded during the 1992 testing could be used to adjust the rating curves to more accurately predict the levels that would occur under specific drawdown conditions.

The equilibration of gas supersaturated water is another important factor to consider. Unfortunately, very little equilibration occurs in the reservoirs and only moderate equilibrations occurs in deep free-flowing rivers like the Columbia and the Snake. Nitrogen saturation levels recorded in the Columbia River in 1967, 1968, and 1969 (Figure 5) show that there was essentially no equilibration occurring in the unimpounded river stretch from Bonneville to Longview, Washington. On the basis of this observation, there is little reason to expect much equilibration to occur in the Snake River, even if there is 3 or 4 miles of free-flowing river created downstream from Lower Granite Dam to the Little Goose pool.

It is highly likely that high levels of gas supersaturation (above 125%) will occur downstream from Lower Granite Dam if a majority of the water is spilled. While these conditions may favor decreased smolt travel time, the benefits must be weighed against the risk of increased gas bubble disease and its possible consequences to adult and juvenile salmon as well as resident fish.

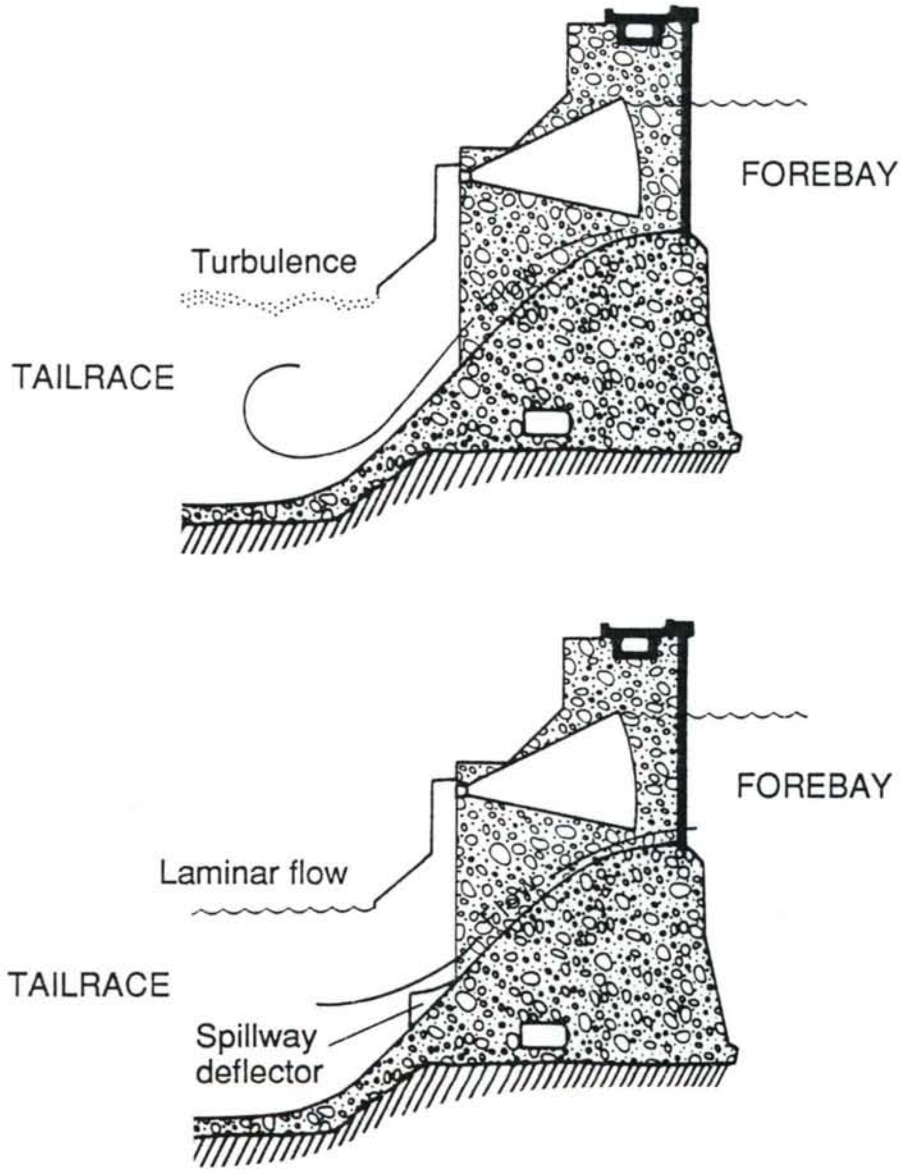

Figure 3. Spillway deflector installed at Lower Granite Dam.

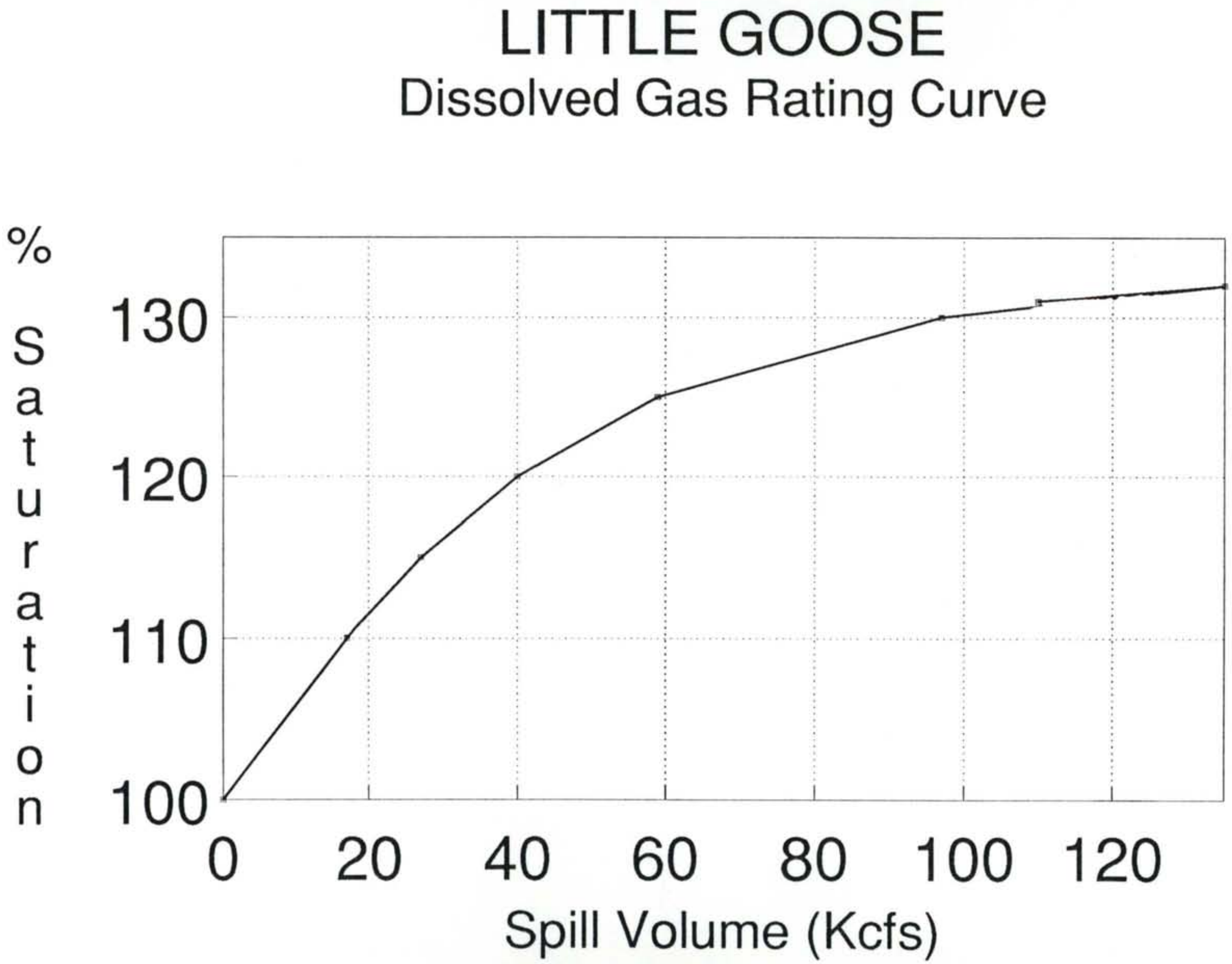

Figure 4. Spillway rating curve for dissolved atmospheric gas obtained at Little Goose Dam from several years' data following installation of spillway deflectors.

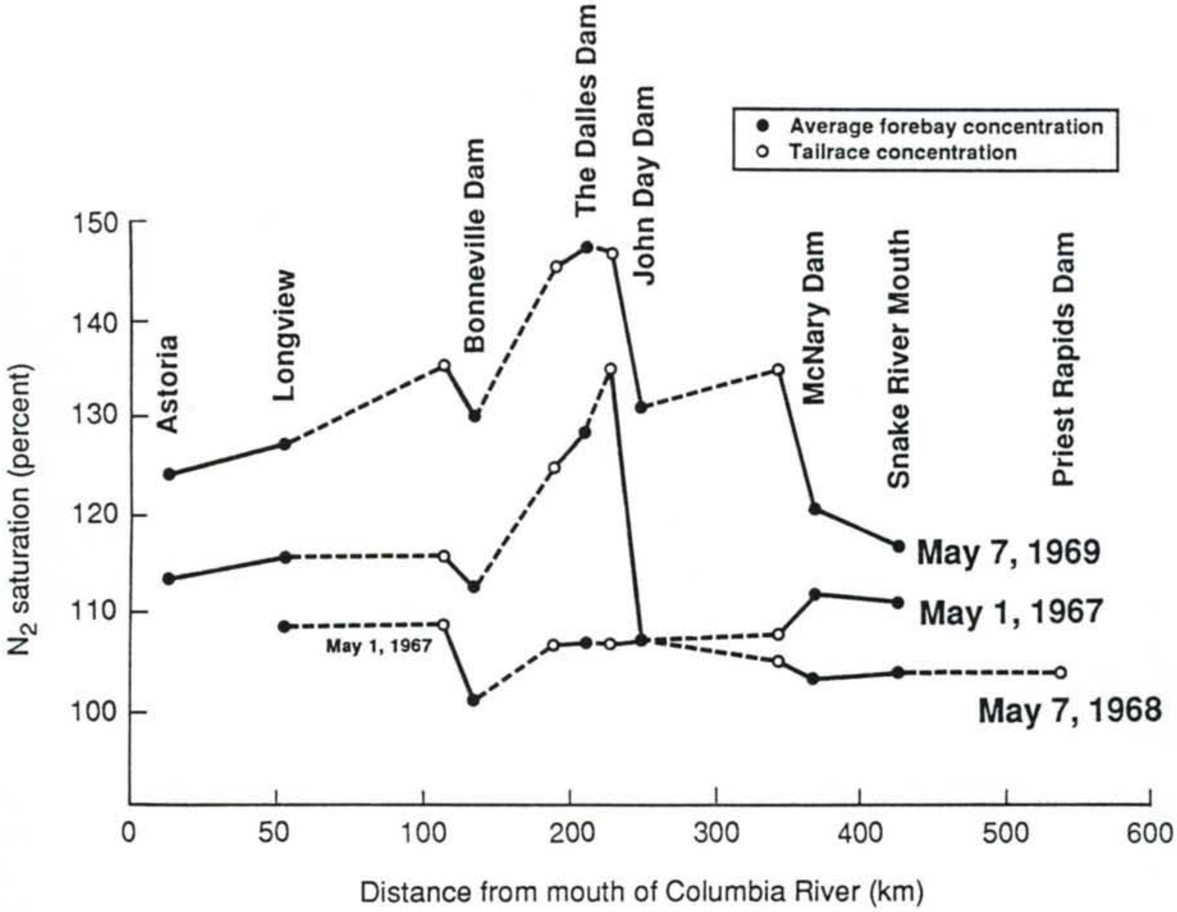

Figure 5. Nitrogen saturation levels in the Columbia River (May 1967, 1968, and 1969).

Salmon Kill below John Day Dam

The proposed drawdown of Lower Snake River dams may put all or most of the river into spillage from spring through fall. During this period, adult salmon and steelhead would pass upstream through this reach and be affected by whatever conditions result. A similar circumstance existed at John Day Dam in 1968, and its results may be instructive, if not predictive of what might happen to adult salmon on the Snake River during drawdown and heavy spill.

John Day Dam closed before the power house was ready and it was necessary to spill virtually all of the Columbia River flow. By mid-July, it was clear that fish passage was abnormal and later, that a fish kill was in progress. Both Beiningen and Ebel (1970) and Bouck et al. (1976) investigated adult salmon off the southern entrance to the fish ladder and reported that adult summer chinook, adult sockeye salmon, and other fish species were dying of gas bubble disease. Lesions included emboli in blood and emphysema in various tissues. After the fish kill, Charles O. Junge (Fish Commission of Oregon), estimated "that over 20,000 summer chinook salmon from the 1968 spawning population were missing between Bonneville and McNary Dams" (Beiningen and Ebel, 1970). This estimate was based both on fish passage records and on the observation of 365 adult chinook salmon carcasses. If the observed carcasses represented 2.65% of the kill (per Merrill et al. 1971), then at least 13,774 adult summer chinook died, a figure that is probably less than the total kill.

The exact number of dead adult and juvenile chinook will never be known, in part because crews buried dead adult salmon (personal communication, Charles Junge, Fish Commission of Oregon, Portland), thus limiting the number of carcasses to be included in the observed kill. Latent mortality could not be factored into the total kill estimate, but many believe that it accounts for significant additional mortality among Snake River adult spring chinook. Fallback and other counting errors may have impacted the estimated number of dead adults, but probably did not change the order of magnitude of the kill. The impact to smolts in this reach was not determined.

The stock identity of the dead adult chinook remains uncertain, but the combined total summer chinook redd count for the South Fork Salmon River and Johnson Creek in 1968 was only 642 or 55% of the previous five-year average of 1161 redds per year (listed in Fish Hatchery Evaluations-Idaho, Idaho Department of Fish and Game, February 1990). While other explanations are possible, the reduced number of redds supports the contention that large numbers of Snake River summer chinook adults were killed by gas supersaturation in this incident. Because the summer chinook population was already too low to allow a fishery, the 1968 loss was particularly significant, both quantitatively and qualitatively.

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Residualism of Salmonid Fishes in Lower Granite Reservoir, Idaho-Washington

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Introduction

The decline in numbers of salmon in the Snake River system has aroused so much concern that in April 1992 chinook salmon were classified as a threatened species. Juvenile mortality of chinook salmon is one key area affecting abundance (Giorgi 1992). Survival estimates suggest significant smolt loss from upstream release or rearing sites to Lower Granite Dam. As a result, areas where chinook salmon numbers can be affected are being examined. The importance of flows during downstream migration is one area of interest. Low flows reportedly increase travel times through the system and contribute to low juvenile survival. Longer travel times increase opportunities for predation and decrease "motivation" for downstream migrating smolts, which could ultimately result in residualism in the reservoirs. Therefore, high rates of residualism could account for low survival estimates at Lower Granite Dam. This paper assesses the significance of residualism by salmonid fishes in the lower Snake River reservoirs.

Sources of Residualism

During smoltification, morphological, behavioral and physiological changes occur in juvenile fish that enhance survival in a marine environment. Although smoltification has been widely investigated and the process is generally understood, few studies have examined the process of desmoltification. Desmoltification could account for reduced motivation to migrate downstream, possibly correlating with residualism. During desmoltification, smolts lose their motivation to migrate downstream and may stay in rivers and reservoirs.

Residualism of steelhead *Oncorhynchus mykiss* in streams has been quantified in the Tuccannon River, Washington, and reportedly accounted for about 4% of the fish that were considered suitably sized (Mark Schuck, Washington Department of Wildlife, Dayton, Washington, personal communication). Nothing has been found in the literature on salmon residualism in streams. Residualism in the streams, however, probably could not account for the low number of smolts that arrive at Lower Granite Dam.

Residualism in reservoirs potentially accounts for decreased numbers of downstream migrating smolts, especially during low flow years. For example, in 1977, a low-flow year, steelhead smolts were reportedly abundant in all of the lower Snake River reservoirs (Wes Ebel, National Marine Fisheries Service, Seattle (retired), personal communication) and contributed to a significant sports fishery. The quantification of residualism, other than indirect assessment through the contribution to the sports fishery, has not been conducted.

Estimation of the temporal and spatial relative abundance of smolts has been part of a multiyear study to assess the effects of dredging and in-water disposal of sediment in Lower Granite Reservoir. Aspects of this study were initiated in 1985 (Bennett and Shrier 1986) and have been generally conducted annually to date (Bennett et al. 1988, 1990, 1991). Although the focus of these studies is to assess the effects of in-water disposal of sediment in Lower Granite Reservoir, fish collections have provided information on the abundance of salmonid fishes in Lower Granite Reservoir prior to, during, and following the time considered by biologists to be the downstream migration period for salmon spp. *Oncorhynchus* and steelhead.

General Findings

Catches of chinook salmon *O. tshawytscha* along the shoreline by beach seining during the day and by and electrofishing at night, and in open water by purse seining or surface trawling, were high from mid-April through May of 1988 to 1991. In general, June catches in both open water and along the shoreline decreased, suggesting that most chinook salmon and steelhead had moved through Lower Granite Reservoir.

The two flow years of 1987 and 1990 indicate a good contrast of flow conditions in Lower Granite Reservoir. In 1987, inflows peaked from mid- to late May and then decreased. In 1990, a later peak flow occurred in the end of May and inflows remained fairly high through mid-June. The timing of inflows appeared to be as significant as the actual flow.

In 1987, catches of chinook salmon along the shoreline by nighttime electrofishing and daytime beach seining were high in Lower Granite Reservoir, especially during late April (Figure 1). Sampling results from May and early June indicated that numbers declined in the reservoir, which suggested that most of the chinook salmon emigrated from Lower Granite Reservoir and residualism was low. The numbers of steelhead collected in the reservoir were almost the reverse of the chinook catches: they were low in April and May but continued to increase into mid-June (Figure 1). Steelhead were also visibly abundant in the reservoir and were apparently residualizing. Sampling results from the summer of 1987 supported high catch rates in early to mid-June. Catch rates of steelhead in gill nets remained high in Lower Granite Reservoir throughout the summer, which suggested the abundance of steelhead was comparable to that of northern squawfish and largescale suckers (Figure 2), two of the more abundant fish in the lower Snake River reservoirs (Bennett et al. 1983).

The abundance of steelhead in Lower Granite Reservoir seems to be closely associated with inflows to the reservoir (Figure 1). Flows in 1987 peaked from the end of April to mid-May, then decreased through June. Our catch data indicate that some steelhead emigrated from Lower Granite Reservoir through May, but after flows declined in mid-May they continued to collect in the reservoir. Declining flows in 1987 apparently contributed to the great abundance of steelhead and residualism in the reservoir.

In 1990, catches of chinook salmon in Lower Granite Reservoir were high along the shoreline and in open water through April (Figure 3). Catches in early and mid-May were generally lower than in April, suggesting that many fish emigrated from the reservoir. In late May, however, catches increased at a time when juvenile chinook salmon numbers are usually declining in Lower Granite Reservoir. The high numbers of juvenile chinook suggested that numerous chinook remained in Lower Granite Reservoir and that many of these fish might residualize. However, inflows to Lower Granite Reservoir in 1990 were different from those in 1987. Late spring rains and upper-elevation snowmelt contributed to increased flows in late May that created a stimulus for downstream migration; thus numbers of chinook in Lower Granite Reservoir decreased substantially. The higher flows in late May apparently provided stimuli to motivate the juvenile chinook salmon in the reservoir to emigrate. Catch data indicated that by mid-June most juvenile chinook salmon had emigrated from Lower Granite Reservoir.

Based on our sampling from 1987 to 1991 (Bennett et al. 1988, 1990, 1991), the incidence of residualism of chinook salmon in Lower Granite Reservoir is low. In 1987, however, residualism by steelhead was significant. Catch rates of salmonids within Lower Granite Reservoir appear to be related to the time of year and inflows. Our data indicate that increased inflow during the latter part of the downstream migration period of chinook salmon and steelhead from Lower Granite Reservoir is important to lessen the potential for residualism.

The relationship between catch rates, which are probably indicative of high number of salmonids in Lower Granite Reservoir, and flows is not clear from these data. A high number of smolts, presumably residualizing, seem to remain in Lower Granite Reservoir when flows decrease in late May and June without an increase in inflow. Although the evidence is highly indirect, the data suggest residualism does occur in Lower Granite Reservoir, especially for steelhead. Based on our data, few chinook salmon remained in Lower Granite Reservoir after June, and residualism has not accounted for a significant number of juvenile salmon that did not arrive at the dam. Residualism of steelhead in Lower Granite Reservoir during flow years similar to 1987, however, can be significant.

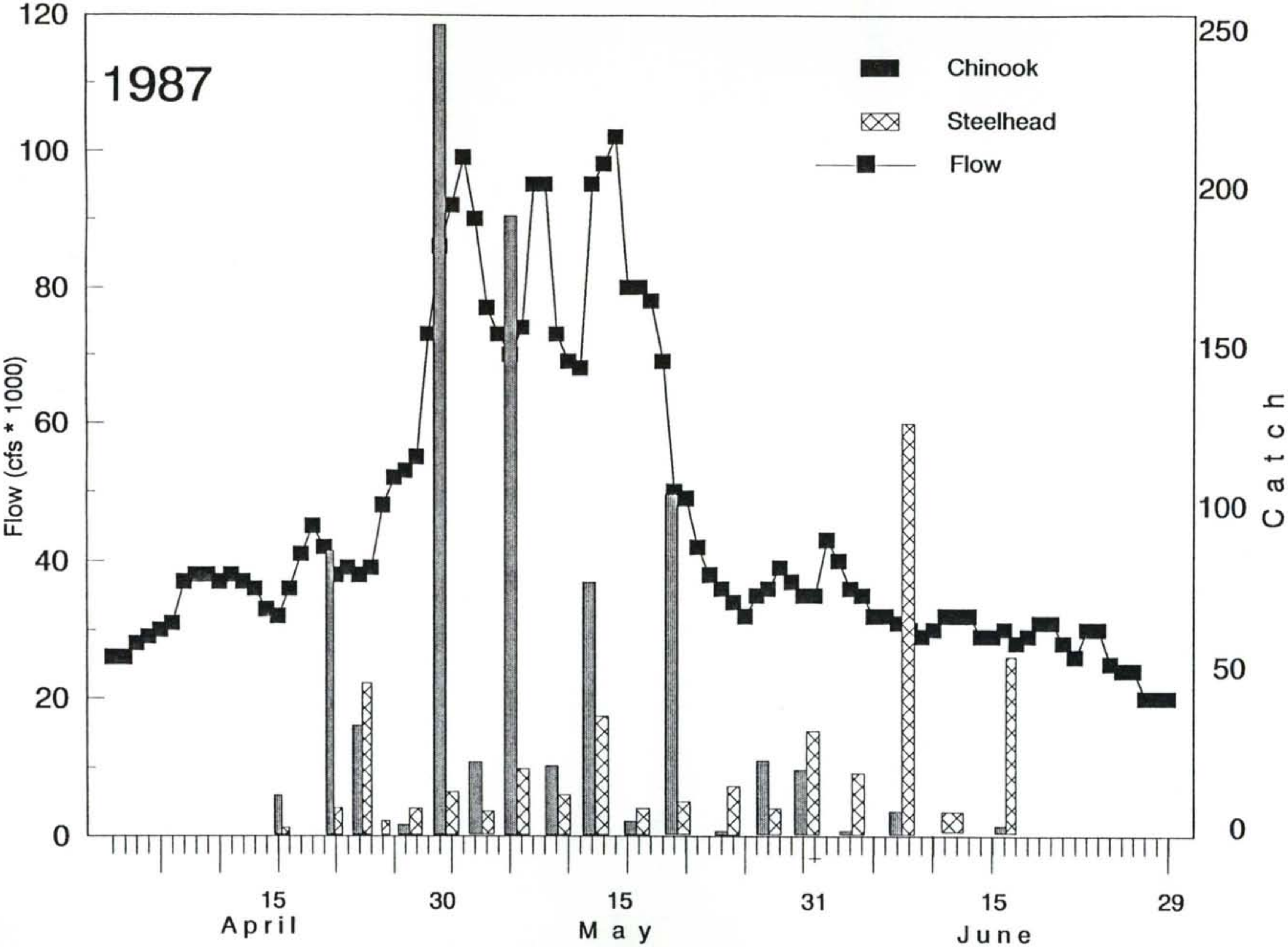

Figure 1. Relationship between inflow to Lower Granite Reservoir, Idaho-Washington, and captures of chinook salmon and steelhead by beach seining and electrofishing during the spring of 1987.

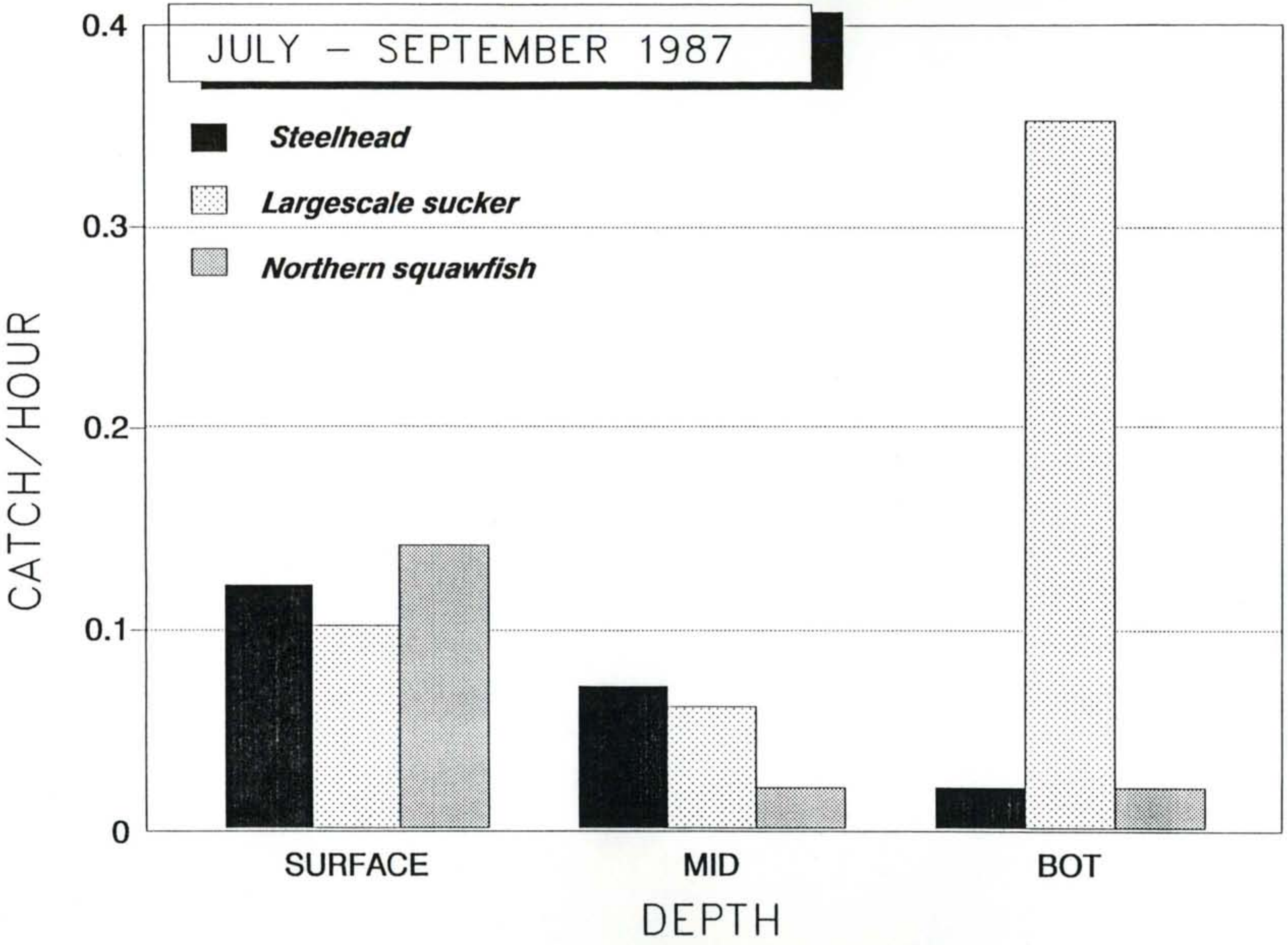

Figure 2. Catch-per-effort for gill nets fished at the surface, mid-water, and bottom in Lower Granite Reservoir, Idaho-Washington.

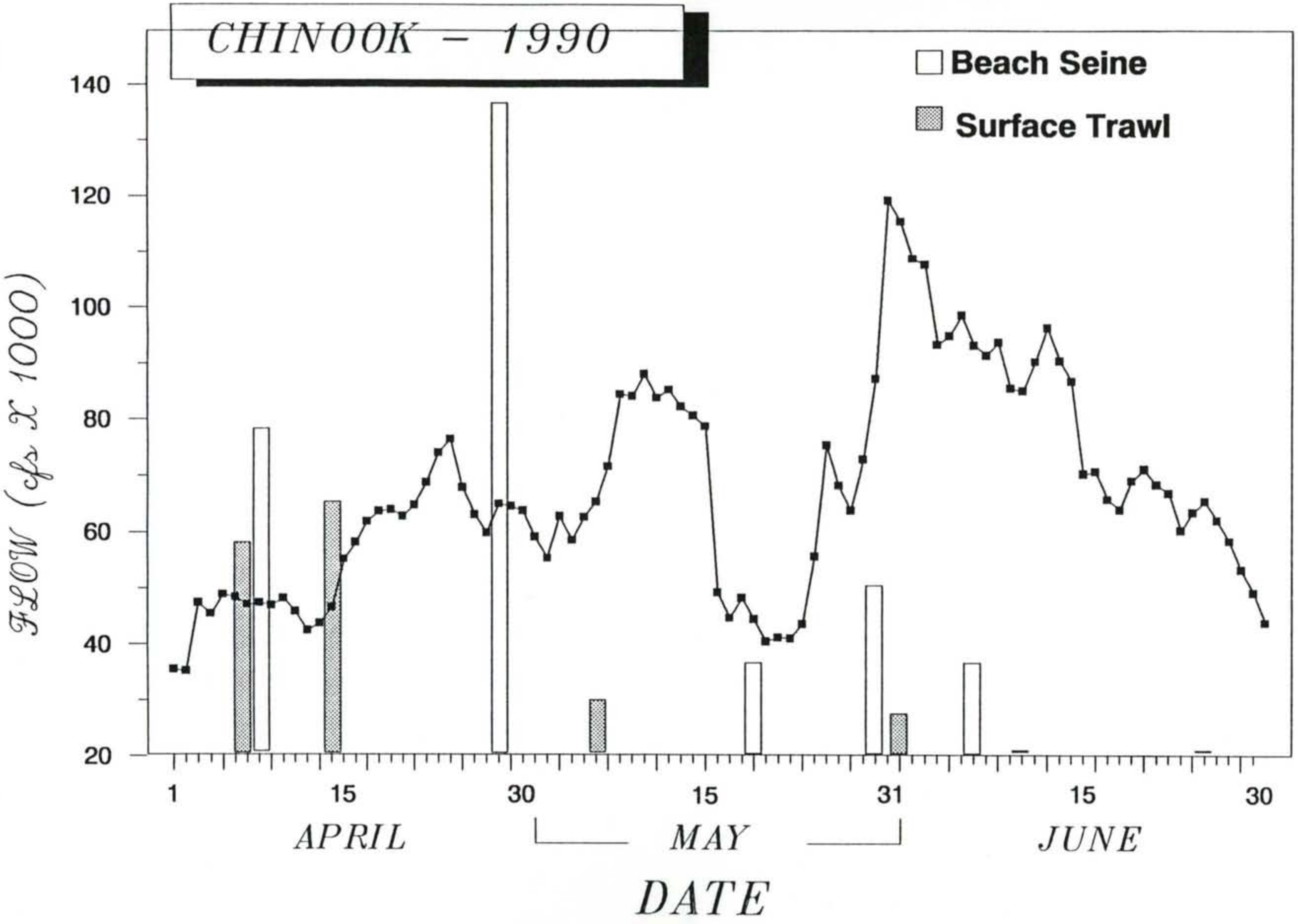

Figure 3. Relationship between in-flow to Lower Granite Reservoir, Idaho-Washington, and captures of chinook salmon by beach seining and surface trawling during the spring of 1990.

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A Comparison of PIT-Tagged Spring and Summer Chinook Salmon Detection Rates with Snake River Flows at Lower Granite Dam

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Introduction

The decline in abundance of many stocks of anadromous salmonids is a major environmental concern in the Pacific Northwest. For example, wild Snake River spring/summer chinook salmon runs have declined drastically over the last 30 years. In addition, adult return rates of hatchery populations of the same species have been disappointingly low.

The hydropower system on the Columbia and Snake Rivers has clearly been a major factor in the 30-year decline of indigenous stocks, as well as an important contributor to the continued depression of these fish. This has occurred despite aggressive actions and measures to increase smolt survival during passage through the system. One such action has been the effort to increase river flows during the spring and summer out-migration. Some have postulated that a substantial decrease in smolt travel time through the system is the key to increasing survival, and that this could be achieved by simply increasing water flows to increase water particle travel time velocity. However, our analysis of recent data on PIT-tagged fish indicates that the timing and movement of some smolt populations do not respond consistently to different flows within or among years.

Methods

Since 1988, National Marine Fisheries Service researchers have PIT-tagged large numbers of chinook salmon fingerlings in natural rearing areas and hatcheries in Idaho (Matthews et al. 1990). Fish were tagged at Lookingglass and Sawtooth Hatcheries in 1988 (out-migration year 1989), and Dworshak and Sawtooth Hatcheries in 1989 and 1990 (out-migration years 1990-91). The out-migration patterns of fish from these hatcheries are generally representative of those from most upper Snake River basin hatcheries.

In all 3 study years, wild summer chinook salmon were tagged in streams in the South Fork of the Salmon River in Idaho and in the Imnaha River in Oregon. In 1988, the wild spring chinook salmon were from streams in the upper Salmon and Clearwater Rivers in Idaho, and the upper Grande Ronde River in Oregon, all of which have had some hatchery influence. In 1989 and 1990, most of the wild spring chinook salmon were from the Middle Fork of the Salmon River, where there has been no significant hatchery influence.

During their seaward migration the following spring, tagged fish were detected as they passed through the bypass systems at Lower Granite, Little Goose, and McNary Dams. Data analyses included a comparison of PIT-tag detections at Lower Granite Dam to flows measured at the dam by the U.S. Army Corps of Engineers.

Results and Discussion

In 1989, 1990, and 1991, flows at Lower Granite Dam differed substantially during the spring salmonid out-migration, particularly prior to 14 May (Figure 1). In 1989 flows reached a high of over 121,000 cubic feet per second (cfs) in mid-April. In contrast, 1991 flows through the first week of May were similar to the record low flows of 1977. If flows were the only factor affecting smolt travel time, the arrival time of the fish at Lower Granite Dam should have been considerably different between 1989 and 1991.

In each of the study years, hatchery fish contributed about 90% to 95% of the out-migrating fish. Despite the very different flows for the 3 years, there was virtually no difference in the arrival times of the fish at

Lower Granite Dam (Figure 2). By 14 May in all 3 years, over 95% of the hatchery spring chinook salmon detected had passed Lower Granite Dam.

Arrival times of wild summer chinook salmon at Lower Granite Dam varied considerably among years (Figure 3). In 1990, possibly because of higher temperatures due to an earlier spring, the fish arrived at the dam earlier than in 1989 or 1991. However, once the fish began moving through the dam, their movement pattern was virtually identical over the 3 years.

Wild spring chinook salmon are thought to leave their over-wintering habitat over an extended period; therefore, relating their movement through the dam to flow is problematical. Nonetheless, prior to 14 May, their pattern of movement through the dam (Figure 4) tended to show virtually no difference over the 3 years studied. The wild spring chinook salmon reacted to the earlier, warmer spring of 1990 similarly to the wild summer chinook salmon by moving through the dam earlier than in 1989 or 1991. After 14 May, fish movement followed periods of heavy rainfall in Idaho and Oregon which caused surges of water, as well as increased turbidity, to reach the dam. Fish in these peaks were, however, primarily from one or two streams, and the peaks occurred almost simultaneously with increased flow at the dam. This suggested that these fish were just upstream from the dam and moved through it quickly by the sudden increase in water discharge. Whether these fish would have moved through the dam in the same timing pattern if the sudden increase in water flow had not occurred is unknown.

In conclusion, observations at Lower Granite Dam indicated that prior to 14 May in 1989-91 (by which time 90-95% of the out-migration had passed), flow had little effect on the dynamics of the out-migration of hatchery or wild spring/summer chinook salmon populations. There was virtually no difference in fish movement patterns for the 3 years in each of the three groups of chinook salmon. Since flow at Lower Granite Dam had little effect on the passage pattern of PIT-tagged fish, we believe that other environmental and physiological factors, in addition to flow, influenced the movement patterns of fish.

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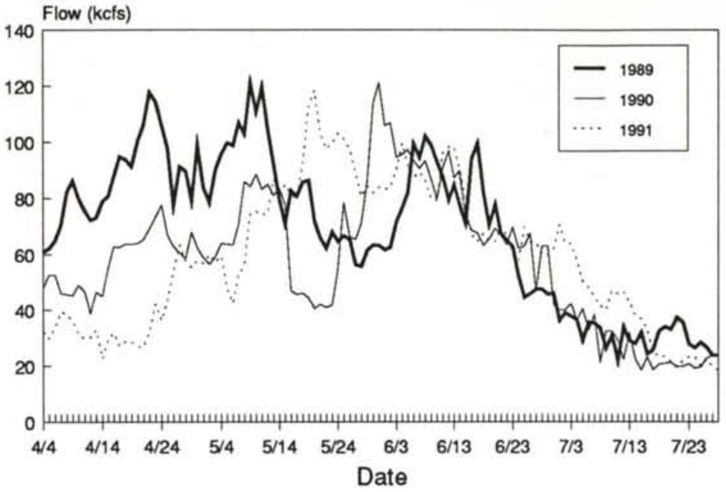

Figure 1.--Snake River flows during outmigration 1989-91.

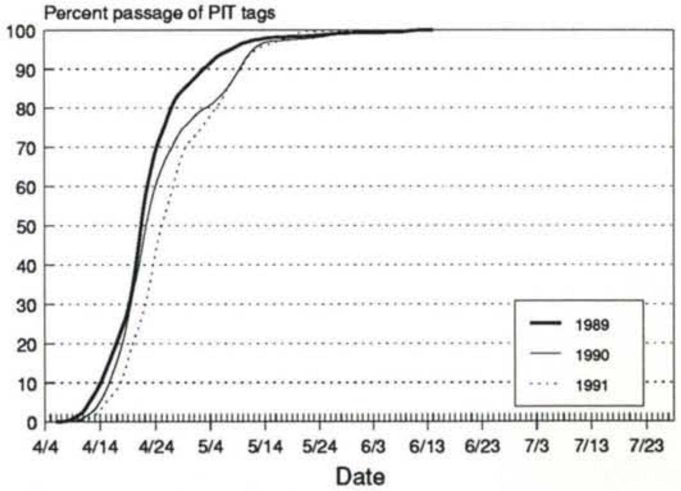

Figure 2.--Hatchery spring chinook salmon, detected at Lower Granite Dam, 1989-91.

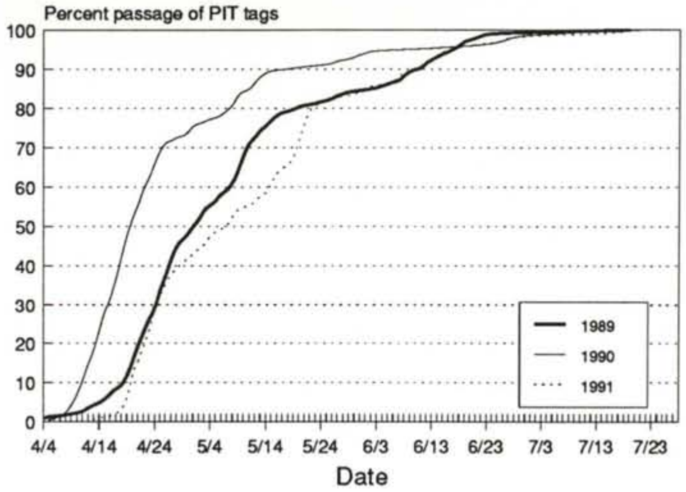

Figure 3.--Wild summer chinook salmon, detected at Lower Granite Dam, 1989-91.

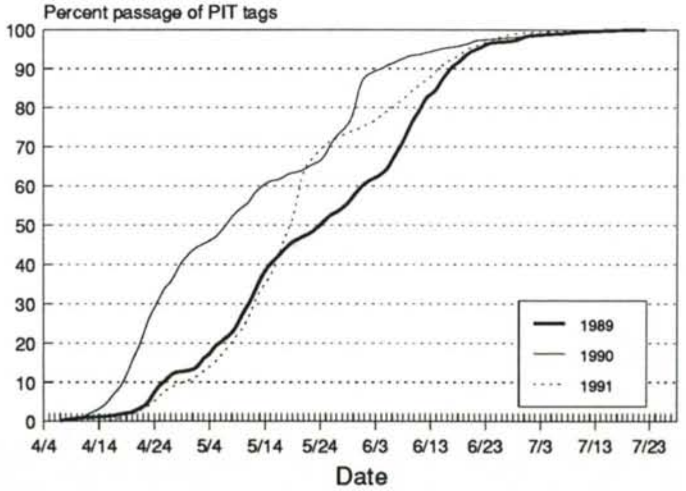

Figure 4.--Wild spring chinook salmon, detected at Lower Granite Dam, 1989-91.

Effects of Flow and Smoltification on the Migration Rates of Spring Chinook Salmon

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Introduction

Understanding the relationships between fish behavior, river flow, and migration rates is paramount to the effective management of the juvenile salmon migrating seaward through the Columbia and Snake rivers. With such an understanding, managers can best use the limited available water for the greatest benefit to the fishery resource. To this end, data has been collected from juvenile salmonid migrants to estimate migration time through index reaches of the Columbia and Snake rivers. Both river flows and the behavioral disposition to migrate were proposed as variables related to the migration time through index reaches. The behavioral disposition to migrate changes during the parr-smolt transformation, a process known as smoltification.

Gill Na^+-K^+ ATPase enzyme activity was selected as a measure of smoltification on the basis of previous investigations. Elevated gill ATPase activity is one component of smoltification, a complex process that includes physiological and behavioral changes that accompany downstream migration. The gill ATPase enzyme is involved in the ion transport mechanism of the gill tissue, one of the changes involved in the transformation of freshwater-adapted "parr" to seawater-adapted "smolts." This is a summary of analyses of gill ATPase activity levels, river flows, and migration times of juvenile spring chinook salmon.

Methods

Analyses of river flow, migration time, and smoltification of juvenile spring chinook salmon were conducted using fish migrating through a 51.5 km (32 mi) index reach of the Snake River between the Idaho Fish and Game Snake River Trap, river kilometer (Rkm) 224.5, and Lower Granite Dam, Rkm 173, during 1989 and 1990 (Figure 1). Juvenile spring chinook salmon migrants were sampled from the catch of the Snake River Trap at the upstream end of the index reach. Biweekly groups of 10 fish were sacrificed in a lethal dose of MS-222, and gill filaments were removed for determination of gill ATPase activity. Gill ATPase activity was assessed using the method of Zaugg (1982) with minor modification. Other fish were injected with passive integrated transponder (PIT) tags by the Idaho Department of Fish and Game (Buettner and Nelson 1990a, 1990b) and were released from the trap on the same days. Sacrificed fish were assumed to be representative of those marked with PIT tags, from which migration time information was collected through the Smolt Monitoring Program (Fish Passage Center 1990, 1991).

Stepwise multiple regression was used to analyze the pooled data from 1989 and 1990 (SAS 1988). The criterion for entry or exit from the models was set conservatively at $P \leq 0.15$. In all regressions migration time was the dependent variable and flow and gill ATPase activity were used as independent variables. All variables were natural-log transformed for best fit.

Two methods were used to determine the relative influence of the gill ATPase activity and flow variables in the multiple regression explaining the migration time of spring chinook salmon. In the first, simple regressions using flow or gill ATPase activity to explain migration time were created and r^2 values were compared. In the second, the multiple regression was used. In this method, each independent variable was varied by one standard deviation from the mean while the other was held constant at the mean value. The influence of each independent variable was then assessed by comparing the changes in migration time due to changes of one standard deviation of each independent variable.

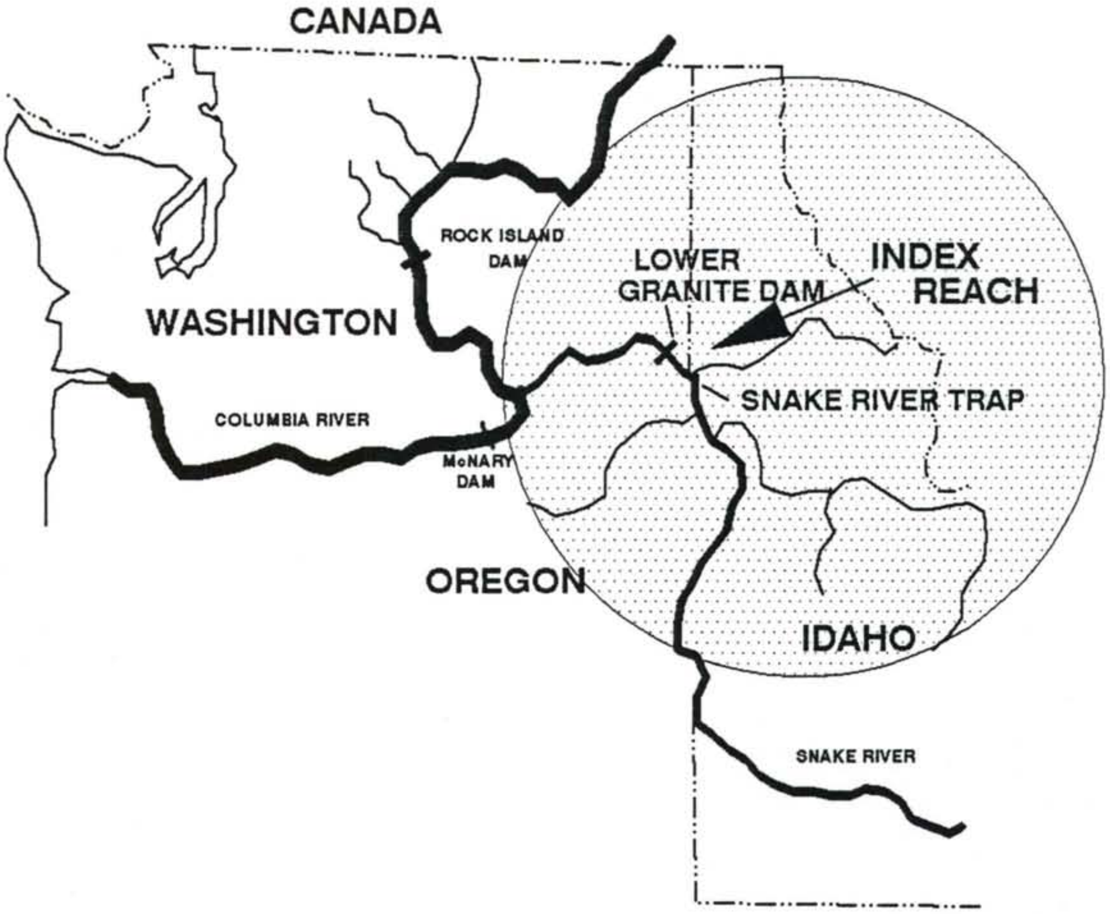

FIGURE 1.—Map of the Columbia River basin showing the Snake River Trap to Lower Granite Dam index reach on the Snake River.

Migration time and flow data were from the annual reports of the Fish Passage Center, Fish Passage Managers (Fish Passage Center 1990, 1991). Data used in the regression analysis are included in Table 1. Data from releases of PIT-tagged spring chinook salmon made on 18 May 1989 at the Snake River Trap were omitted from the analyses since subyearlings may have been present in this sample. (Buettner and Nelson 1990a).

Results

The relationship between the migration time of spring chinook salmon juveniles and river flow variables was different in 1989 and 1990 (Figure 2). In individual years, the migration time and flow relationship was relatively linear, but when both years were pooled, large between-year differences made flow a poor predictor of migration time. These differences could be described by the use of an interaction term, such as a variable including year in the regression equation. However, data in Buettner and Nelson (1990b) indicates the relation between flow and migration time in 1989 was not typical of those from other years during 1987 to 1990. Therefore, additional data will be needed to determine if an interaction term is justified.

Both flow and gill ATPase activity were significant variables in the model of spring chinook salmon migration time. The regression equation is:

$$\log_e \text{MIGTIME} = 7.89 - 0.654 \log_e \text{FLOW} - 1.012 \log_e \text{ATPASE}$$

where $\log_e$MIGTIME = natural logarithm of median migration time in days, logeFLOW = natural logarithm of the average flow (kcfs) at Lower Granite Dam from the date of release to the median date of recapture, and logeATPASE = natural logarithm of mean gill Na^+-K^+ ATPase activity in μmoles P · mg $\text{prot}^{-1} \cdot \text{hr}^{-1}$. This equation had an $R^2 = 0.63$ and was based on a sample size of N = 18 release groups.

In a comparison of the influence of each independent variable using simple regressions, the flow model explained 17% of the variability in migration time, whereas gill ATPase activity accounted for 56%. Using the multiple regression, when both flow and gill ATPase were at their mean levels the predicted migration time through the index reach was 6.9 days. When flow was held constant at the mean (mean= 83.7 kcfs, SD = 15.1) and gill ATPase activity was increased by one standard deviation above its mean (mean = 20.5 μmoles P · mg $\text{prot}^{-1} \cdot \text{hr}^{-1}$, SD = 5.8), the predicted migration time decreased from 6.9 days to 5.4 days (22%). When flow was increased by one standard deviation and gill ATPase activity was at its mean, the predicted migration time decreased from 6.9 days to 6.2 days (10%). A decrease in gill ATPase activity of one SD from the mean resulted in an increase in the predicted migration time from 6.9 days to 9.7 days (40%). Decreasing flow by one SD from the mean resulted in an increase in the predicted migration time from 6.9 days to 7.9 days (14%). Thus, each method of comparison indicated that both flow and gill ATPase activity played roles in the migration time of spring chinook salmon through the Snake River Trap to Lower Granite Dam index reach.

Using the multiple regression, a family of curves was plotted to represent predicted migration times for various flows and gill ATPase activities (Figure 3). Three conclusions can be drawn from Figure 3. First, as flow and gill ATPase activity increased, the predicted number of days required to migrate through the index reach decreased, indicating both flow and gill ATPase activity were negatively correlated with migration time. Second, an increase from 10 to 20 μmoles P · mg $\text{prot}^{1} \cdot \text{hr}^{-1}$ gill ATPase activity resulted in a greater reduction in migration time than did an increase from 30 to 40 μmoles P · mg $\text{prot}^{-1} \cdot \text{hr}^{-1}$ of gill ATPase activity. This indicated that the greatest effects of changes in gill ATPase activity were early in the smoltification process. Third, the negative slope of the lines describing the effects of gill ATPase activities on migration time is greatest at low values of the flow variable, indicating that changes in gill ATPase activity had the greatest effects on migration times at low flows.

TABLE 1.—Data used in regression analyses of migration time, gill ATPase activity, and flow. Data was collected from juvenile spring chinook salmon migrating in the Snake River Trap to Lower Granite Dam index reach during 1989 and 1990. Flow is the daily average flow (kcfs) over the period from the median date of release from the Snake River Trap through the date preceding the median date of detection at Lower Granite Dam. Migration time and flow data are from Fish Passage Center Annual Reports (1990, 1991).

MULTI-DAY	MEDIAN	--ATPase--		FLOW	-----MIGRATION TIME---	
RELEASE	RELEASE DATE	MEAN	N		MEDIAN	NUMBER DETECTED
	03/29/89	10.7	20	73.8	19.1	55
	04/04/89	13.0	10	79.1	15.5	52
	04/06/89	10.8	10	80.7	12.8	33
	04/11/89	16.7	10	90.8	11.5	54
	04/13/89	18.3	9	91.7	8.7	53
	04/18/89	19.0	10	103.0	5.1	65
	04/20/89	24.1	10	109.6	4.7	59
	04/25/89	22.0	10	87.1	7.1	70
	04/27/89	24.3	10	86.8	6.5	66
5/02-5/03	05/02/89	30.9	10	97.9	4.4	19
	05/11/89	19.0	10	89.3	5.9	65
	04/19/90	16.3	9	68.9	5.6	54
	04/20/90	17.1	9	69.4	5.6	59
	04/26/90	24.7	10	61.2	8.8	44
4/27-4/28	04/27/90	25.2	10	61.0	8.4	28
5/01-5/05	05/01/90	23.3	17	65.3	8.1	34
5/09-5/13	05/10/90	24.3	22	84.5	4.0	48
5/31-6/01	05/31/90	29.5	18	107.2	4.4	41

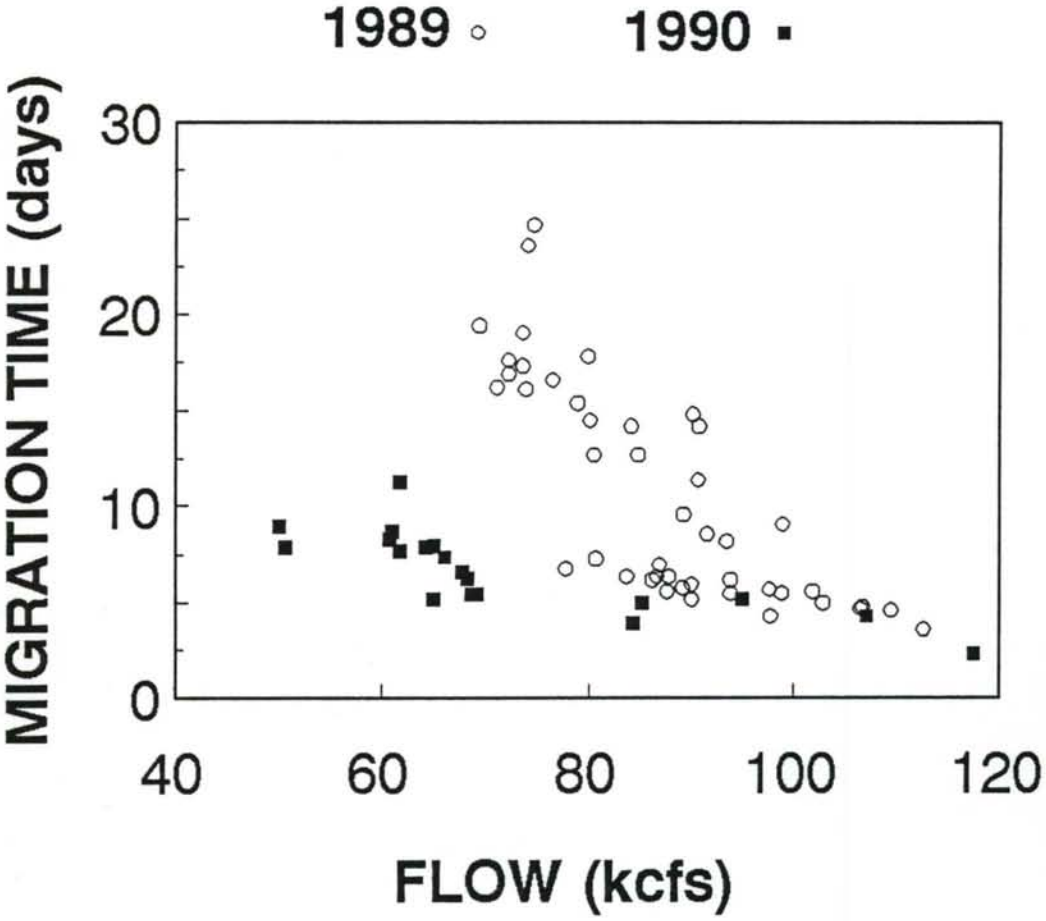

FIGURE 2.—Migration time (days) from the Snake River Trap to Lower Granite Dam and flow (kcfs) at Lower Granite Dam for spring chinook salmon juveniles PIT-tagged at the Snake River Trap in 1989 and 1990. Data are from Fish Passage Center Annual Reports (Fish Passage Center 1990, 1991).

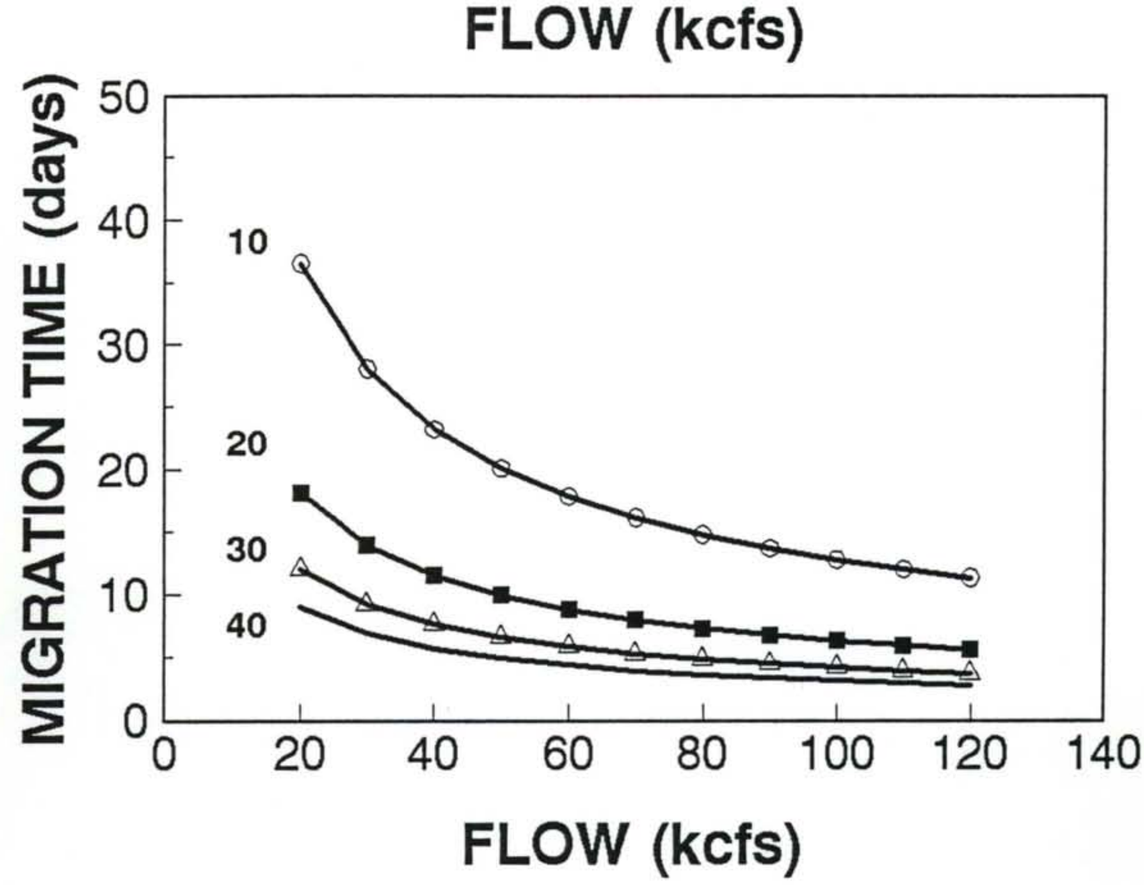

FIGURE 3.—Predicted migration time and flow relationships of juvenile spring chinook salmon migrating through the Snake River Trap to Lower Granite Dam reach at four gill ATPase activities (10, 20, 30, 40 μmoles P · mg prot^{-1} · h^{-1}. Data points were generated using a multiple regression.

Discussion

Research under this project was based on the hypothesis that both river flow and degree of smoltification play roles in fish migration behavior. Since river flows in any one year tend to be less variable than flow regimes between years, a multiyear database will be needed for a thorough analysis of this relationship. Our results were based on a limited data set from two years of data collection. Flow and migration time data used in these analyses were a subset of that available to other investigators since gill samples for determination of gill ATPase activities were taken two days per week, whereas releases of PIT-tagged fish were made each day. Therefore, results from these analyses should be evaluated with caution, since trends evident in larger data sets of migration time and flow (Fish Passage Center 1990, 1991; Buettner and Nelson 1990a, 1990b) may not be discernable with the sample sizes from our collections in 1989 and 1990.

The model of spring chinook salmon migration time in the Snake River Trap to the Lower Granite Dam reach indicates both flow and gill ATPase activity are important variables in explaining variation in spring chinook salmon migration time. Although the gill ATPase variable appeared to be more influential than the flow variable, the data collected in 1989 and 1990 had a narrow range of river flows, resulting in a smaller standard deviation for flow than would be expected if the data included a wider range of flows. With a larger standard deviation the influence of the flow variable would have been greater.

The effects of gill ATPase activity were greatest as gill ATPase activity increased during the early stages of smoltification, with effects diminishing as flows increased. This observation could be a valuable tool for use in the management of spring chinook hatcheries. For example, previous work indicates that as spring chinook salmon were released from many hatcheries in Washington and Idaho, their gill ATPase activities were at about 10 μmoles P $\cdot$ mg prot^{-1} $\cdot$ hr^{-1} (units) and were often rising (Beeman et al. 1990, 1991; Rondorf et al. 1988, 1989). Using Figure 3 and assuming a flow of 40 kcfs at Lower Granite Dam, a gill ATPase activity of 10 units results in a predicted migration time of about 23 days. If fish were held in the hatcheries until their gill ATPase activities had increased to 15 units, the predicted migration time would be about 15 days. In this scenario, using a small increase in gill ATPase activity results in a decrease in predicted migration time of 8 days, a 35% reduction for fish migrating through the 51.5 km (32 mile) index reach.

Summary

1. Both river flow and gill ATPase activity, a measure of smoltification, explained significant amounts of the variability in estimates of the migration time of spring chinook salmon. Together, these variables explained 63% of the variability in migration time estimates of spring chinook salmon.

2. The effects of gill ATPase activity on the migration time of spring chinook salmon appeared to be greatest early in the smoltification process and diminished as flows increased. It was proposed that the migration times of spring chinook salmon reared in hatcheries may be reduced by releasing fish with elevated gill ATPase activities.

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Accelerating Smolt Development and Migratory Behavior in Yearling Chinook Salmon with Advanced Photoperiod and Temperature

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Introduction

To improve the survival of downstream-migrating salmonid smolts in the Snake River, traveling screens have been installed at hydroelectric dams to guide smolts away from turbines, and increased flows have been requested to minimize migrational delay. Research on yearling chinook salmon *Oncorhynchus tshawytscha* has shown that their physiological status influences responses to these efforts; yearling chinook salmon farther along in the parr/smolt transformation are guided at a higher rate (Giorgi et al. 1988; Muir et al. 1988, 1990).

Hatchery-reared yearling chinook salmon have an extended residence time in Lower Granite Reservoir and suffer high mortality en route to Lower Granite Dam (Giorgi 1991). Research on their physiological and behavioral development in the hatchery environment has shown that they are often released in sub-optimal physiological condition (Muir et al. 1988; Zaugg et al. 1991). Release dates are often dictated by management concerns unrelated to physiological status (Folmar and Dickhoff 1981). Furthermore, security lights, constant food supply, and stable water temperatures during rearing create environmental conditions that differ substantially from those experienced by juveniles in a natural environment, resulting in fish that may not be physiologically or behaviorally prepared to migrate when released (Nishioka et al. 1985). Incomplete smolt development in the hatchery may be partly responsible for migrational delay and increased mortality among hatchery smolts.

The research described here was designed to determine whether migration speed of yearling chinook salmon could be increased by accelerating smolt development in the hatchery. Previous studies have shown that smolt development in hatchery stocks of steelhead *O. mykiss* may be accelerated by altering environmental conditions, especially temperature and photoperiod, resulting in early migratory movements (Zaugg and Wagner 1973; Wagner 1974).

Methods

Research was conducted over a 3-year period at Dworshak National Fish Hatchery (NFH) (Idaho) to assess the feasibility of accelerating, through artificial means, the physiological development and subsequent migratory behavior of yearling spring chinook salmon (Giorgi et al. 1990, 1991; Muir et al. 1992). Preceding release, treatment groups were exposed to a 3-month advanced photoperiod schedule for 13 to 18 weeks to accelerate smolt development. Metal halide lights (400-watt) were suspended above treatment raceways and regulated with a timer to maintain the desired photoperiod schedule. Additional groups exposed to the advanced photoperiod schedule or ambient light (control) were reared at an elevated water temperature (11-12°C) for 10 to 14 days before release.

Gill Na^+-K^+ ATPase activity was monitored to evaluate physiological development (Zaugg 1982). Treatment and control groups were PIT-tagged (Prentice et al. 1990b) to evaluate median travel time (days) to Lower Granite Dam and detection proportions at Lower Granite, Little Goose, and McNary Dams (Prentice et al. 1990a).

Results and Discussion

Photoperiod and photoperiod + temperature treatments increased gill Na^+-K^+ ATPase activity in yearling chinook salmon at Dworshak NFH to levels significantly higher than in controls at the time of release in

1989 and 1990 (Figure 1). Photoperiod and photoperiod + temperature groups had significantly (Student's t-test, $P < 0.001$) shorter travel times than the control groups to Lower Granite Dam during all years (Figures 2 and 3).

Photoperiod treatment groups had higher overall detection proportions than the control groups; photoperiod + temperature groups had significantly higher detection proportions than the control groups (Figure 4). Increased water temperature, when applied to photoperiod treatment groups 10 to 14 days before release, produced the highest level of smolt development, shortest travel time, and highest downstream detection rate.

Beeman et al. (1992) found significant correlations between migration rate and gill Na^+-K^+ ATPase activity in migrating yearling chinook salmon in different reaches of the Columbia and Snake rivers. In Beeman's model, the greatest increase in migration rate occurred early in the smoltification process when gill Na^+-K^+ ATPase levels were low (about 10 units), but increasing (to 20 units). I observed activity levels similar to these in control and treatment groups at the time of release. Although the increases in gill Na^+-K^+ ATPase activity achieved with photoperiod and photoperiod + temperature treatments were significant, they were far below the levels observed in active migrants captured downstream (Beeman et al. 1992). Thus, if hatchery fish could be induced to develop gill Na^+-K^+ ATPase activities in the 20-unit and above range prior to release, they might exhibit even higher rates of downstream migration.

This study demonstrated that accelerated smolts were more physiologically developed, traveled faster, and were detected in higher proportions downstream. Greater emphasis should be placed on optimizing physiological development and releasing hatchery smolts at times that are conducive to rapid downstream movement and high survival. Maximizing smolt development in hatcheries prior to release would complement efforts to increase migration rates by augmenting river flow. Evaluating additional methods to maximize smolt development in the hatchery would be worthwhile.

Conclusions

1. Photoperiod and photoperiod + temperature treatments increased gill Na^+-K^+ ATPase activity in yearling chinook salmon to levels significantly higher than in controls at the time of release.

2. Photoperiod and photoperiod + temperature groups had significantly shorter travel times than the control groups over the same distance.

3. Photoperiod + temperature treatment groups had significantly higher overall PIT-tag detection proportions than the control groups; photoperiod treatment groups also had higher detection proportions, but not significantly so.

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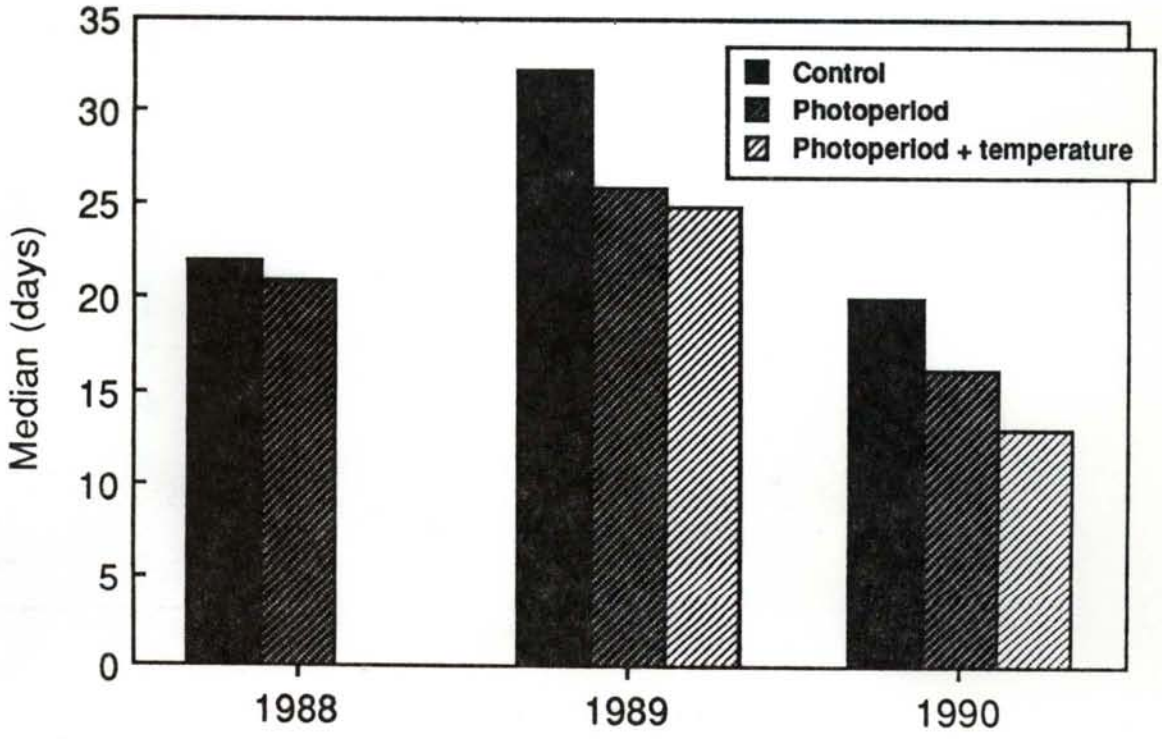

FIGURE 2.—Median travel time to Lower Granite Dam for fish released from Dworshak National Fish Hatchery, 1988-90.

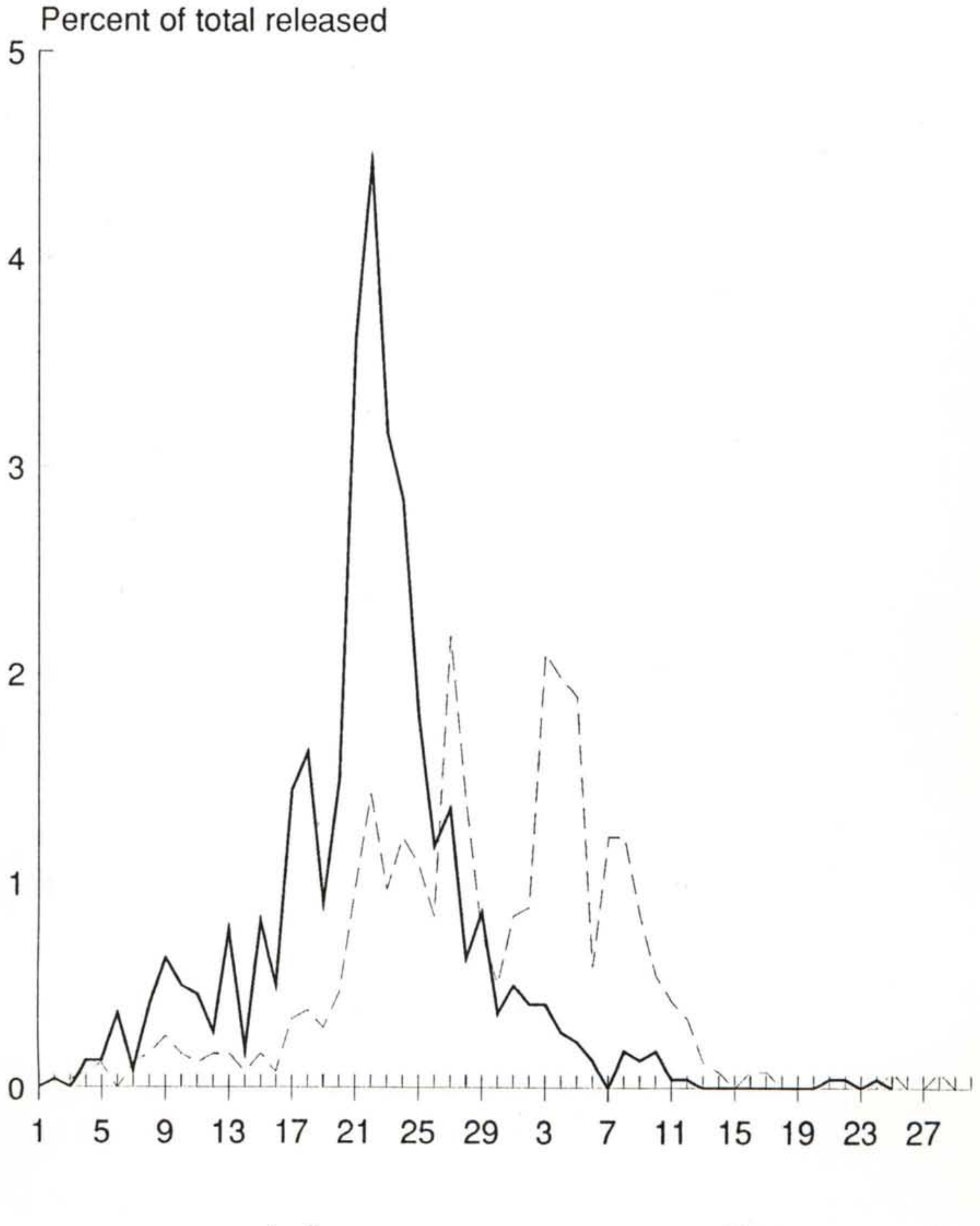

FIGURE 3.—Passage patterns for PIT-tagged control (dashed line) and photoperiod + temperature (solid line) treatment groups at Lower Granite Dam, 1989.

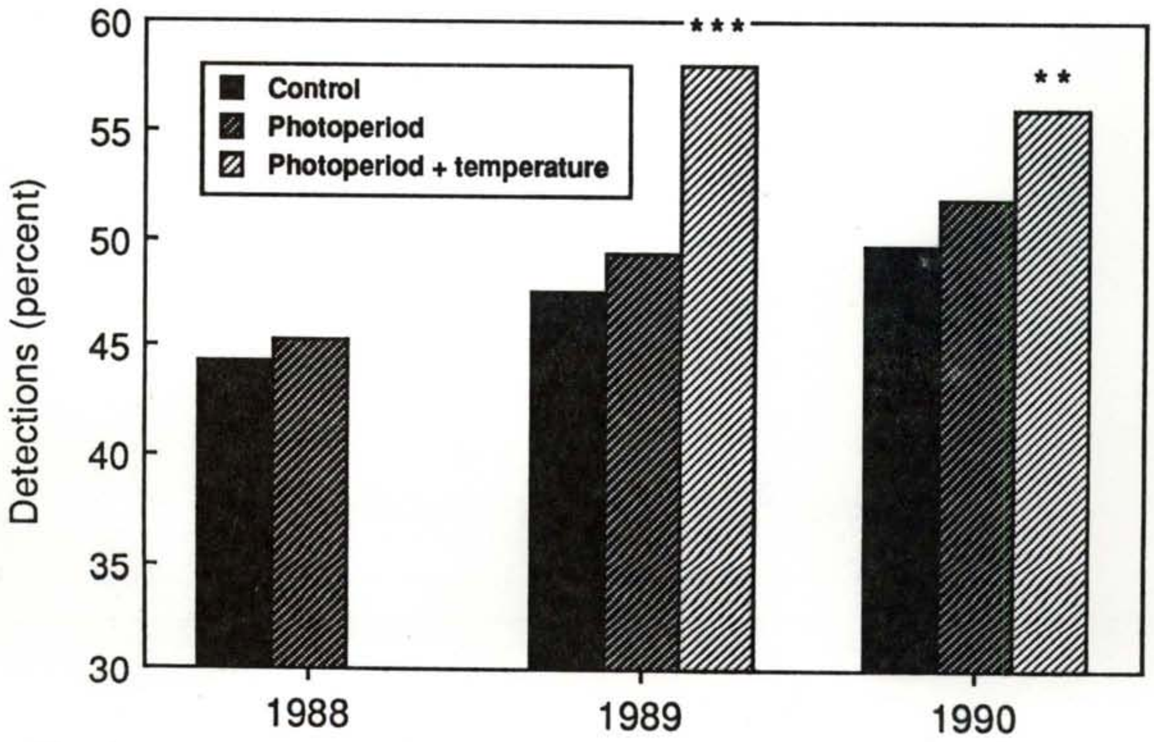

FIGURE 4.—Overall PIT-tag detections (percent of total released) at Lower Granite, Little Goose, and McNary Dams combined, 1988-90 (χ^2: ** = $0.001 < P < 0.01$; *** = $P < 0.001$).

Analysis of Flow and Velocity Effects on Smolt Survival and Adult Returns of Wild Spring and Summer Chinook Salmon

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Introduction

Effective recovery actions for Snake River spring and summer chinook *Oncorhynchus tshawytscha* under the Endangered Species Act will require significant improvements of Snake River mainstem velocities during the smolt migration period (April 15 to June 15)(CBFWA 1991a). Water velocities could be improved with some combination of increased flow (CBFWA 1991a) and drawdown of mainstem reservoirs (Andrus 1991). There is a disagreement in the basin about which approach needs to be implemented, and to what extent it should be implemented. In question is the relationship of smolt migration survival to various reservoir water velocities.

Water velocity is a primary determinant of smolt migration speed (Smith 1982; Buettner in press; Bergren and Filardo 1991). Water velocity in the mainstem Snake and Columbia rivers is controlled by the flow and the storage volume of the reservoirs. Migrating smolts now face water velocities that are 6 to 15 times slower than those under which they evolved (CBFWA 1991b; Figure 1).

During the period 1970 to 1980 the National Marine Fisheries Service (NMFS) estimated total smolt survival through five or six projects, from the uppermost Snake River Dam to The Dalles Dam. Sims and Ossiander (1981) summarized these data and reported a significant positive relationship between flow and survival for yearling chinook and steelhead smolts.

Because of changing conditions at the dams during the NMFS study (Raymond 1979), analysts have more recently attempted to partition reservoir survival from the total survival estimate. The Analytical Methods Work Group (AMWG) estimated reservoir survival as a residual by "backing out" the turbine, bypass, and spill mortality at the dams using standard smolt routing models and annual estimates of mean fish guidance efficiencies and spill proportion (McConnaha 1990). Reservoir survival per mile was estimated as the root of total miles of reservoir. Reservoir mortality per mile was then compared to mean smolt migration flow at The Dalles Dam or Ice Harbor Dam.

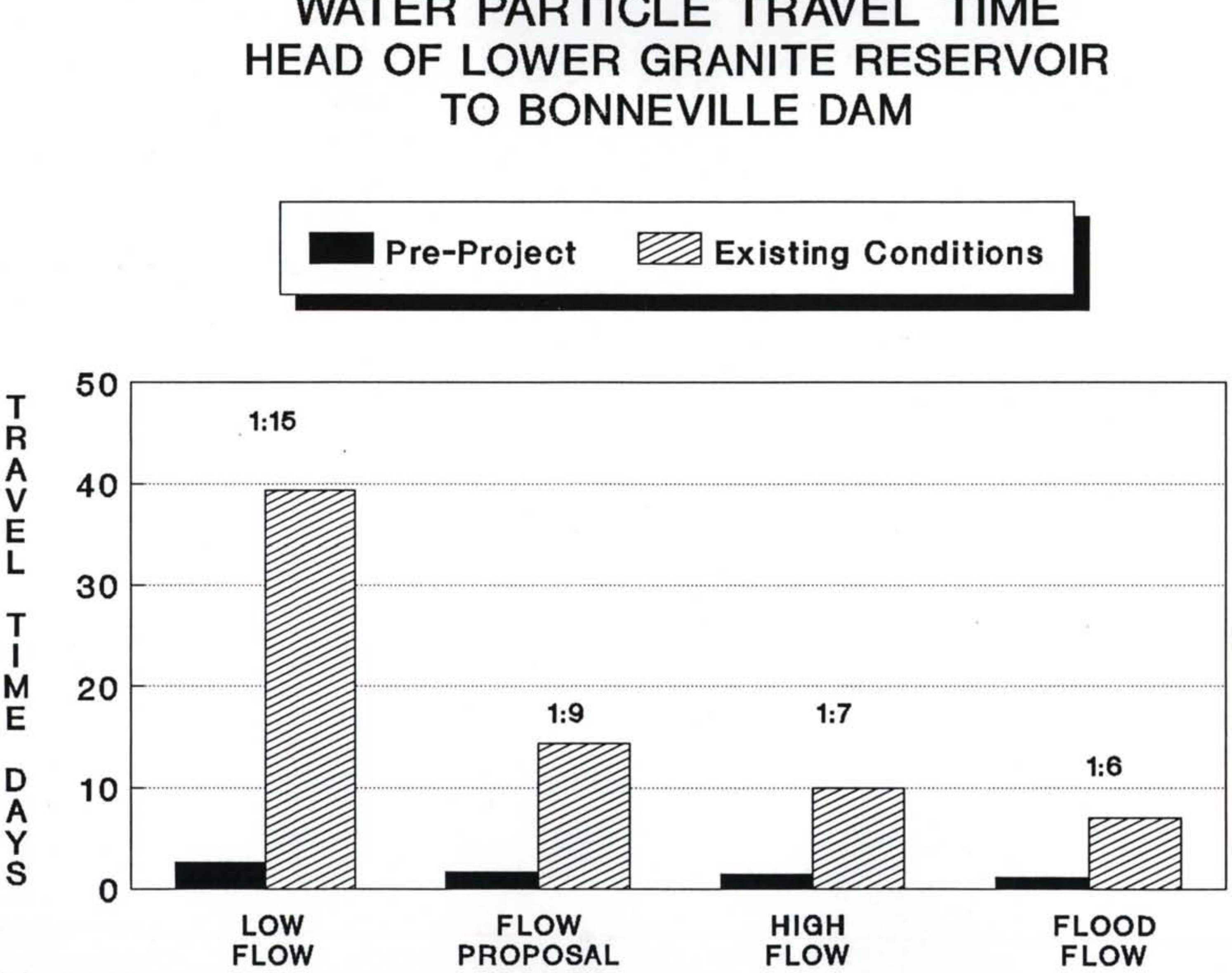
Fundamentally different flow-survival functions have been fit to the AMWG reservoir survival estimates. These functions have implications for the analysis of recovery actions for Snake River spring and summer chinook. Mechanistic models based on these functions should be able to realistically "hindcast" run sizes as well as project the effects of mainstem improvements. Empirically-based adult return rate data are critical in testing the utility of these models and understanding the smolt survival problem.

The objectives of this paper are to present an overview of the NMFS smolt survival data set, analytical methods, and flow-survival relationships, and correlations between adult return rates and numbers of transported smolts and mainstem velocities.

Methods

NMFS Smolt Survival Data Set

An overview of the NMFS data set is presented, and two additional sources of mortality unique to the study period are described, which had not been previously addressed in Sims and Ossiander (1981) or the AMWG estimates. These are gas supersaturation (Ebel 1979) and the slotted gate mortality problems in 1972 at



CBFWA (1991)

FIGURE 1.—Water particle travel time before and after dam development on the Snake and Columbia rivers, from the head of the Lower Granite Reservoir to Bonneville Dam.

Lower Monumental and Little Goose Dams (Raymond 1979). The implications of these factors to alternative flow-survival models are discussed. I also explore an additional data set from Raymond (1979) that provided estimates of wild yearling chinook survival from the Salmon River at Whitebird to Ice Harbor Dam from 1966 to 1975, as additional dams were constructed on the Snake River. Reach survival (minus turbine, bypass, and spill mortality components) from this data set was compared to water particle travel time (Idaho Department of Water Resources, unpublished data).

Adult Returns

I correlated total adult spring and summer chinook returns to Lower Granite Dam with numbers of smolts transported during 1975 to 1988. Equal proportions of age 4 and age 5 adults (Subbasin Planning data, S. Kiefer, Idaho Department of Fish and Game; IDFG) were assumed each year. Two sources of data for smolt-to-adult returns (SAR) were used to correlate to Snake River velocities. The SAR variable is for the most part density-independent, and reflects survival outside the production area.

Estimated SAR for a wild spring chinook population in Marsh Creek, Idaho (Petrosky 1991), was regressed against Snake River water particle travel time (hours from Lewiston to Ice Harbor Dam) for the 1960-87 smolt migrations. To account for reductions in Columbia River harvest rates during the period, the SAR was adjusted to the recent average harvest rate. The adjusted SAR was transformed by natural logarithm and compared to Snake River water particle travel time.

I also regressed the estimated SAR for the aggregate Snake River runs of wild/natural spring and summer chinook and steelhead (Raymond 1988) against Snake River water particle travel time for the 1964-84 smolt migrations.

Results and Discussion

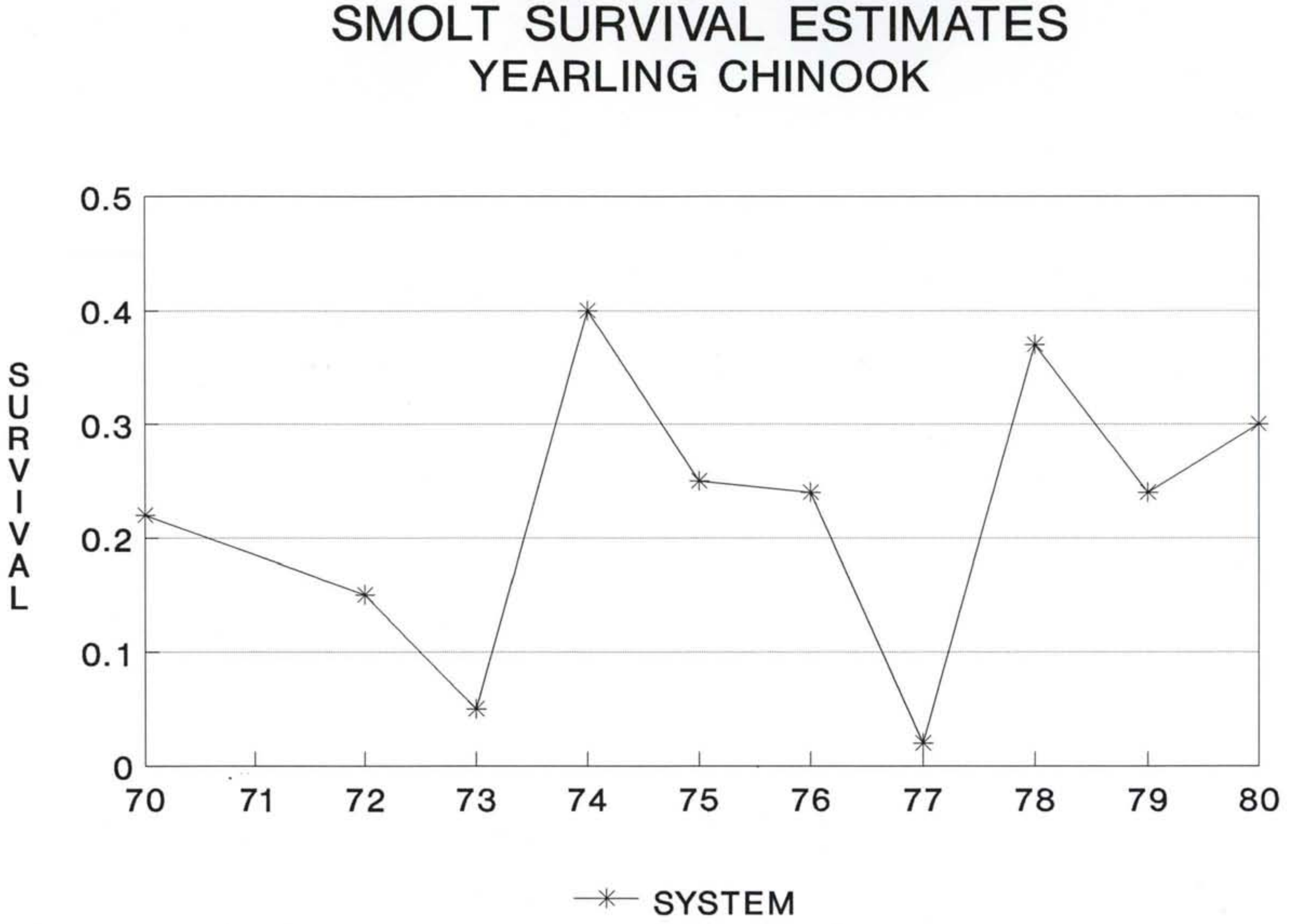
NMFS Smolt Survival Data Set

Annual survival estimates ranged from 2% to 40% for yearling chinook (Figure 2) and from 2% to 67% for steelhead. Smolts survived very poorly in the drought years 1973 and 1977. These two points exert considerable leverage in the Sims and Ossiander (1981) regression for flow and survival.

A similar pattern emerges in the AMWG analysis (McConnaha 1990), where the years 1973 and 1977 again exert major influence. A cursory inspection of the plot of mortality per mile and flow at Ice Harbor Dam (Figure 3) or the Dalles Dam can suggest a number of fundamentally different flow-survival relationships. Depending on the form of the model used, an analysis of options could conclude alternatively that (1) a threshold of 85 kcfs (or equivalent velocity) in the Snake River provides optimal survival; (2) optimal survival occurs between 85 kcfs and 140 kcfs and then survival decreases with flow (polynomial function); or (3) survival increases with flow to 140 kcfs and higher (exponential function).

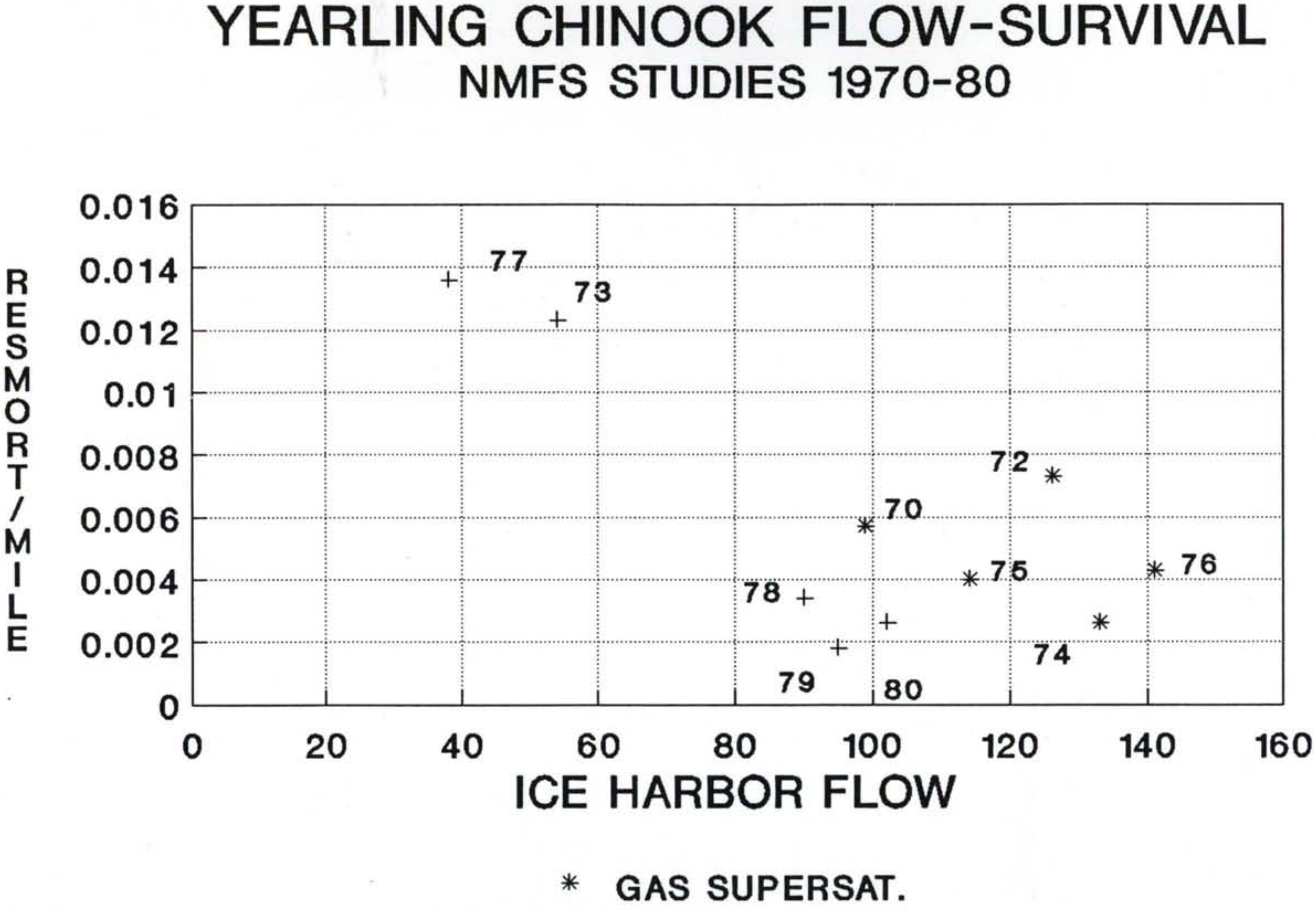
Some review of the causes of smolt mortality during the NMFS studies is necessary to interpret the plots and functions. In high-flow years during the studies, prolonged exposure to lethal concentrations of dissolved gases probably accounted for most of the reservoir mortality (Raymond 1979). In 1972, an estimated 50% of the yearling chinook mortality was related to passage through slotted bulkheads installed at skeleton bays of dams to reduce gas supersaturation (Raymond, 1979).

Neither Sims and Ossiander (1981) nor the AMWG analysis addressed gas supersaturation mortality or the problems unique to 1972 in the flow-survival relationships. Ebel et al. (1975; Tables 11-12) present estimates of mortality relative to gas saturation; mortality increases rapidly between 120% and 130% saturation (Figure 4). Gas supersaturation levels commonly exceeded 120% in 1970-72 and 1974-76 (Boyer 1974; Montgomery and Becker 1980). Since 1977, these high levels have rarely occurred (U.S. Army



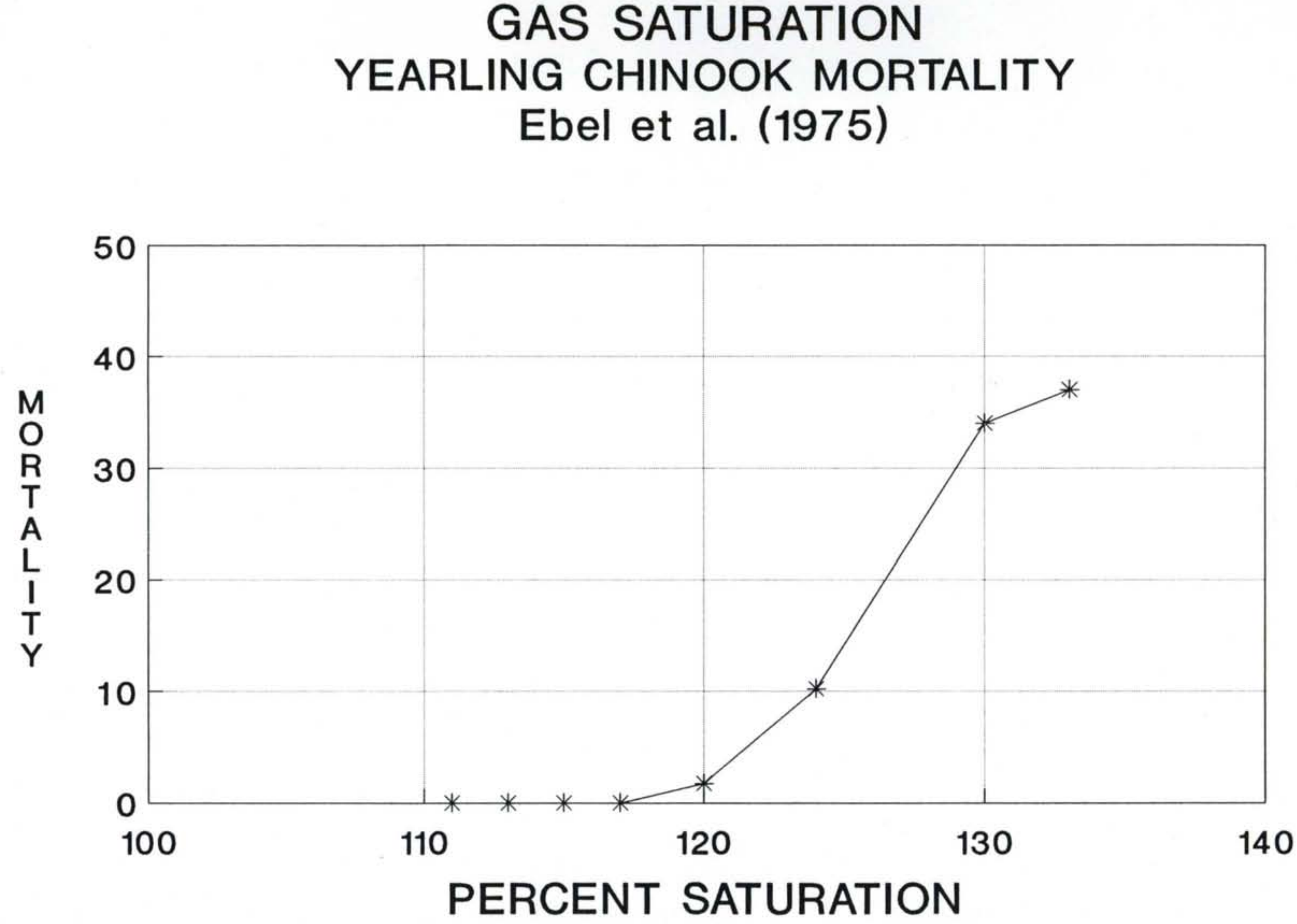
Based on NMFS studies, upper Snake dam to The Dalles Dam.

FIGURE 2.—Annual yearling chinook smolt survival estimates from Upper Snake River Dam to the Dalles Dam, National Marine Fisheries Service studies.



Res-Mort from McConnaha (6/11/90 memo)
Gas supersat. years from Raymond (1979)
1972:slotted bulkead disaster (ibid.)

FIGURE 3.—Reservoir mortality per mile of yearling chinook smolts and mean mainstem Snake River flow (kcfs) at Ice Harbor Dam (4/20-5/30), Analytical Methods Work Group, 1990.



Based on depth distribution of migrants, depth compensation of gas levels and exposure time (Tables 11-12).

FIGURE 4.—Estimated mortality of yearling chinook smolts as a function of percent gas saturation, based on Ebel et al. (1975).

Corps of Engineers data), due primarily to installation of turbines and spill deflectors at the dams (Ebel 1979).

An improved analysis of the NMFS data set would also "back out" the 1972 mortalities and gas supersaturation mortalities noted above, if annual estimates were available. Ebel and Raymond (1976) described a general methodology for estimating this mortality component that incorporates the smolt timing and migration rate, depth distribution, and dissolved gas concentrations. Quantitative assessment of mortalities in these years (coded with an asterisk in Figure 3) is hampered largely by sketchy data on gas concentrations during the early 1970s.

In view of the control of gas supersaturation, the exponential model makes intuitive sense for present conditions, and also mimics the relationship developed between flow and smolt travel time (Bergren and Filardo 1991). It is logical to assume that maximum survival would occur under conditions most similar to those under which the fish evolved.

A common criticism of the NMFS data set is that an increasing hatchery smolt contribution during the period combined with their lower survival rates could bias the flow-survival relationship. Unfortunately, the survival of wild/natural and hatchery chinook smolts cannot be estimated separately in most of the NMFS studies. It should be noted, however, that hatchery releases were relatively constant during the period 1970-80, ranging from 2.7 to 4.0 million smolts (IDFG file data). The major trend in smolt releases was more recent, beginning with 5.5 million in 1983 and gradually increasing to 9.8 million by 1989 due to production from the Lower Snake River Compensation Plan.

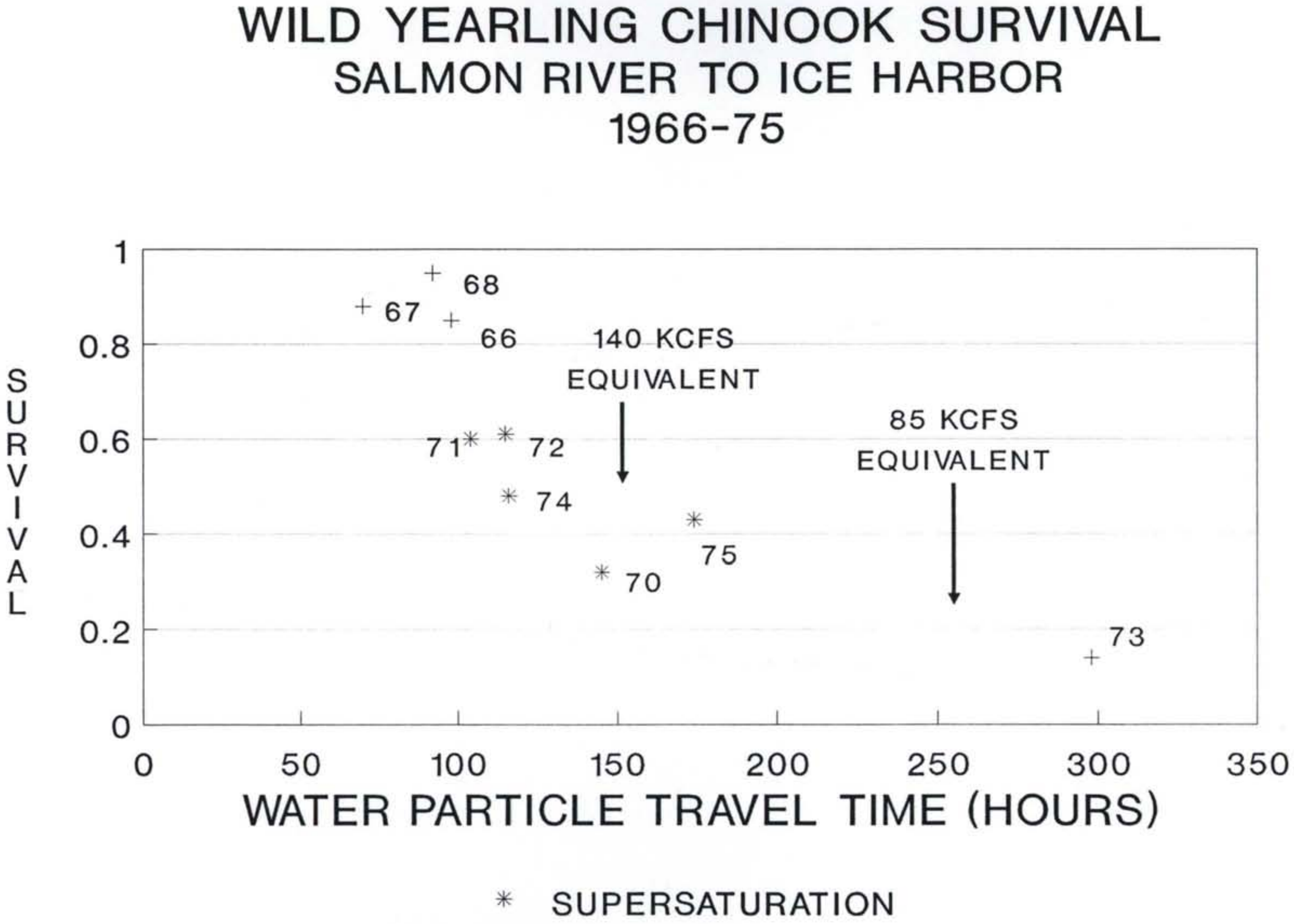
Survival estimates are available for wild yearling chinook from the Salmon River at Whitebird to Ice Harbor Dam during 1966-75 (Raymond 1979). Wild chinook survival decreased from 85-95% with only Ice Harbor Dam to 10-41% with additional impoundments. A regression of river/reservoir survival (using the AMWG methods and parameter values) and water particle travel time (Figure 5) is significant ($r^2 = 0.71$, $P < 0.005$). The regression implies survival benefits to wild fish for mainstem velocity equivalents exceeding both 85 and 140 kcfs (250 hr and 150 hr travel time, respectively).

Adult Returns

Since 1977 an aggressive smolt transportation program has been under way in the Snake River to attempt to compensate for poor in-river survival. Transport benefits have been measured as a ratio of return rates of transported and control groups. The benefits are relative only to in-river survival conditions each year.

Although ratios have generally exceeded 1:1 (Park 1985; Matthews et al. 1990), the transportation program has not rebuilt Snake River runs of spring and summer chinook. A comparison of the numbers of smolts transported and adult returns by smolt migration year (Figure 6) is not significant, and actually suggests a weak negative correlation ($r = -0.39$). The best total returns and return rates were associated with those years with the better flows and smaller proportions of fish transported. In general, the same pattern is apparent both before and after 1983, when hatchery smolt releases increased.

The return rates of wild spring and summer chinook appear to be controlled by the velocities faced during the smolt migration. Smolt-to-adult return for the wild spring chinook population in Marsh Creek, tributary to the Middle Fork Salmon River (Figure 7), was significantly related to water particle travel time ($r^2 = 0.61$, $P < 0.001$). Estimated smolt-to-adult return for Snake River aggregate wild/natural spring and summer chinook (Raymond 1988) show a similar pattern when plotted against water particle travel time (Figure 8). The regression of natural logarithm of SAR and travel time is significant ($r^2 = 0.66$, $P < 0.001$). In addition, smolt-to-adult return for wild/natural steelhead (Raymond 1988), which do transport well, is also significantly related to water particle travel time ($r^2 = 0.48$, $P < 0.001$).



Raymond (1979)
Includes supersaturation morts.

FIGURE 5.—River and reservoir survival of wild yearling chinook from the Salmon River at Whitebird to Ice Harbor Dam, 1966-75, based on Raymond (1979).

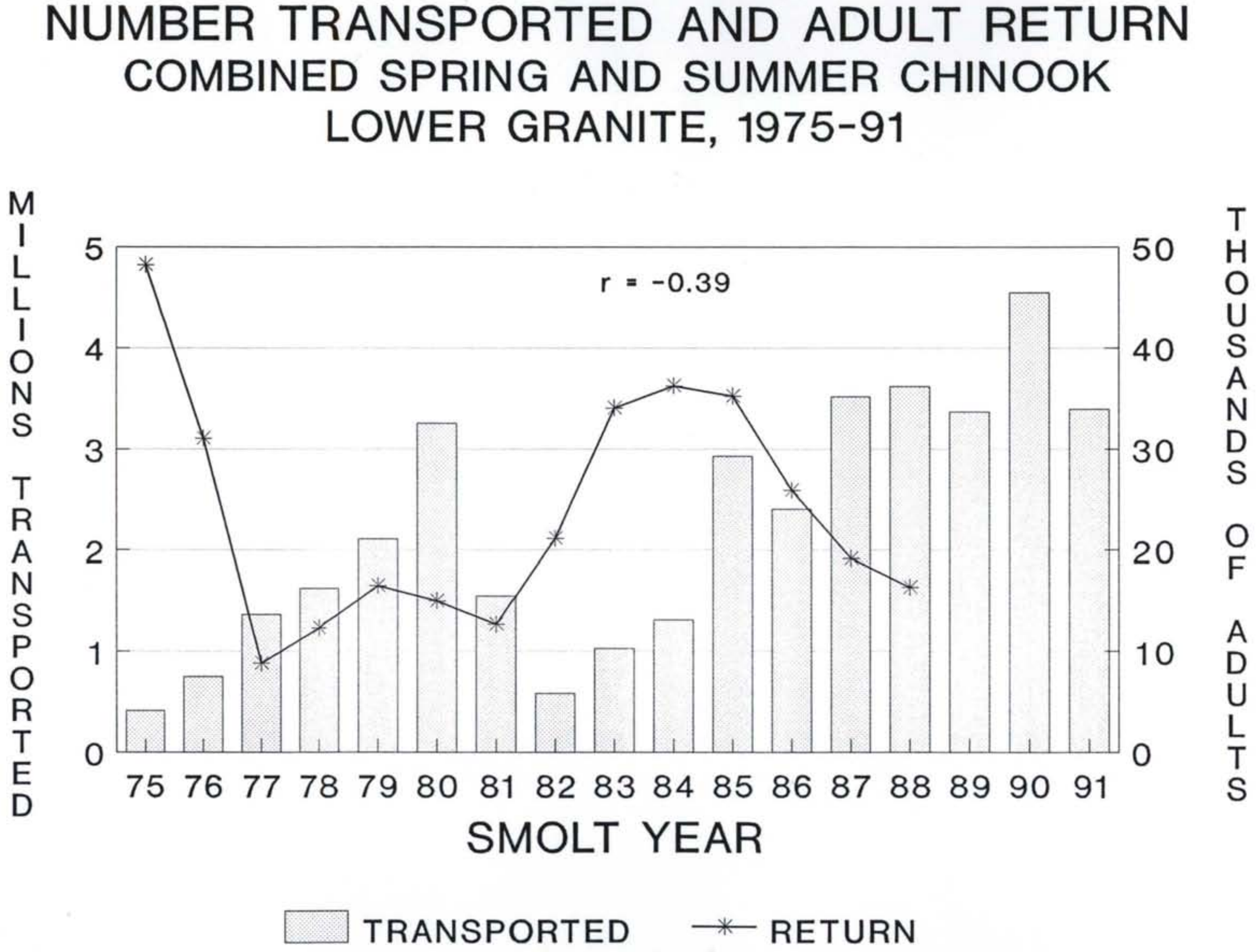
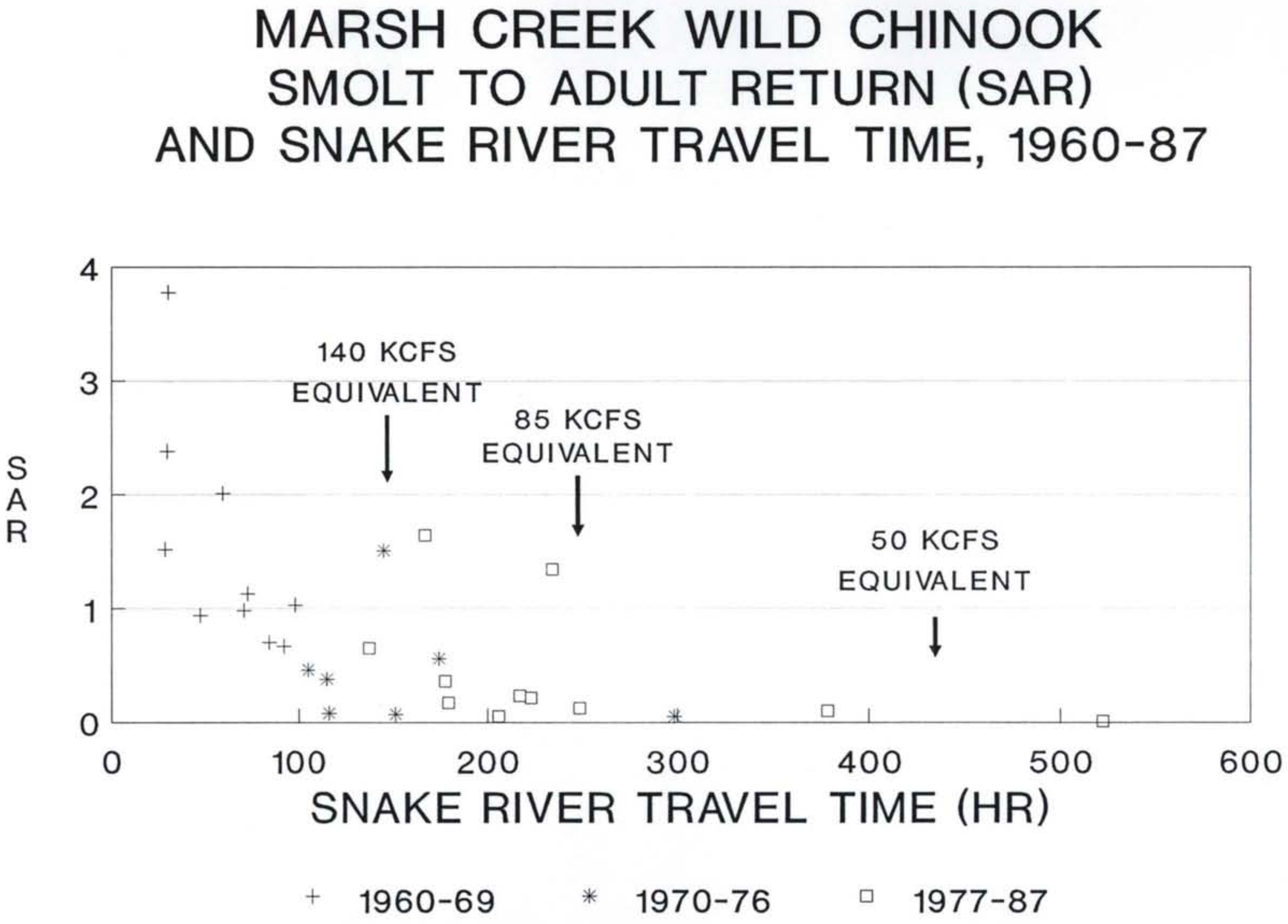
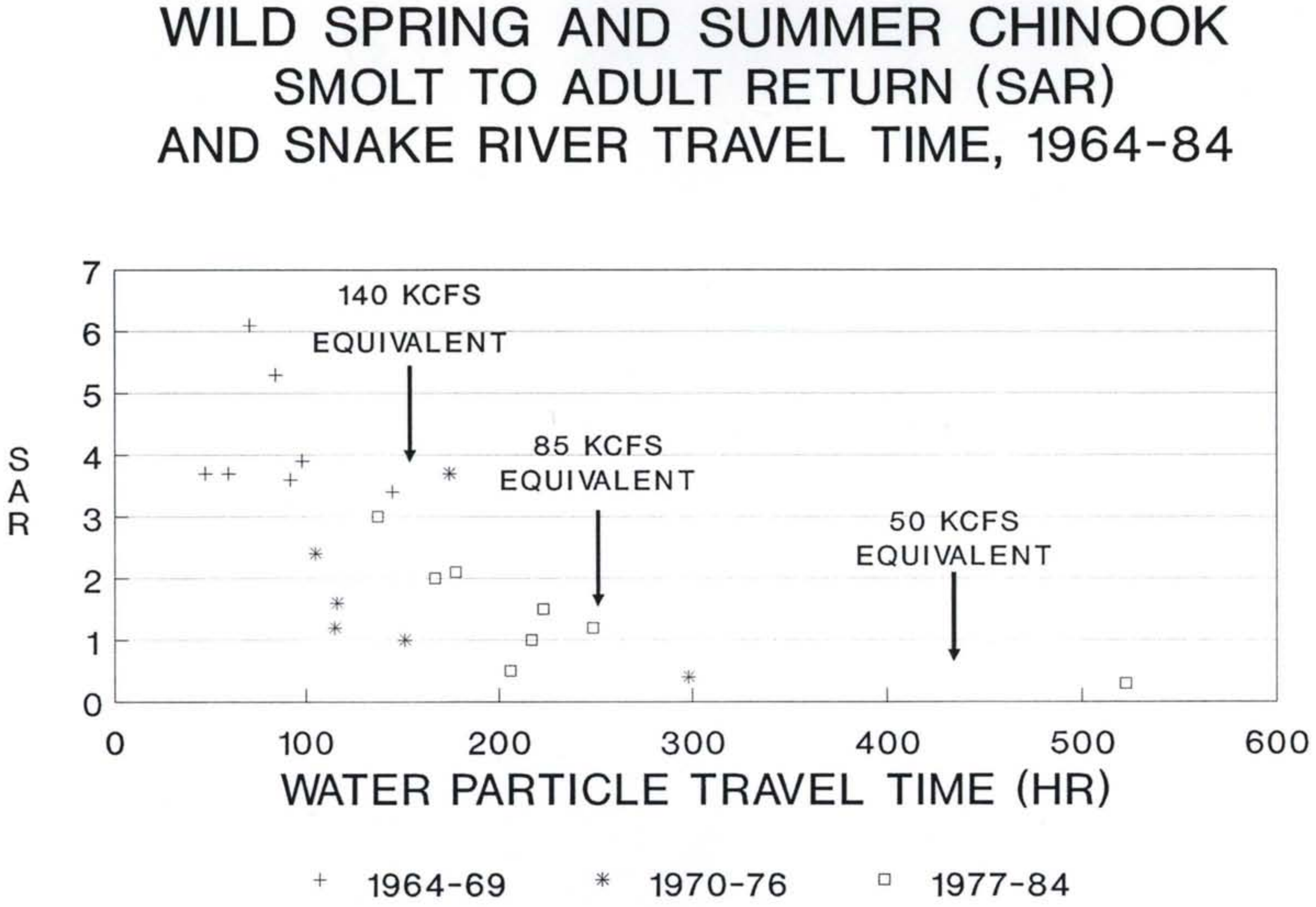


FIGURE 6.—Number of yearling chinook smolts transported and subsequent adult return for aggregate spring and summer chinook of wild/natural and hatchery origin, 1975-88.



SAR FOR 1960-76 ADJUSTED FOR CURRENT MAINSTEM HARVEST RATES

FIGURE 7.—Smolt-to-adult return (SAR) of wild spring chinook from Marsh Creek, Idaho, as a function of Snake River water travel time (hr), 1960-87 smolt migrations.



Raymond (1988): smolts at upper dam to adults at IHR + prior harvest
IDWR data on water particle travel time

FIGURE 8.—Smolt-to-adult return (SAR) of wild/natural spring and summer chinook from the Snake River as a function of Snake River water travel time (hr), 1964-84 smolt migrations, based on Raymond (1988).

None of the relationships suggest any threshold in return rates at velocities slower than those before the Snake River was dammed. Rather, they lend support to conclusions in previous studies of smolt behavior, migration speed, and smolt survival that state the critical importance of flow and water velocity.

Summary

1. Water particle travel time has increased 6- to 15-fold since the impoundment of the Snake and Columbia rivers, and has been associated with decreased smolt travel times, decreased smolt survival, and declining adult returns.

2. Yearling chinook smolt survival rates from NMFS studies in 1970-80 are significantly related to flow and water velocity for aggregate wild/natural and hatchery fish.

3. An overview is presented on the analytical approach commonly used to estimate reservoir survival from the NMFS studies conducted during 1970-80. Sources of smolt mortality unique to the study period have not been isolated from the data set. These are gas-related mortality at high flow and spill, and mass mortalities at slotted gates at two Snake River dams in 1972.

4. The NMFS reservoir survival data set has been fit with functions that imply that survival is optimized at velocities ten times slower than pre-dam velocities, without regard to the unique conditions during the studies.

5. Since the control of gas supersaturation beginning in the late 1970s, a exponential function appears to best describe the relationship between chinook smolt mortality and flow or velocity, where survival reaches an asymptote at pre-dam velocities.

6. Similar analytical methods applied to a data set for wild yearling chinook smolts also imply survival benefits for mainstem velocities exceeding the 140 kcfs full-pool equivalent in the Snake River.

7. No positive relationship was found in a simple regression between numbers of yearling chinook transported and subsequent adult returns. The largest returns were associated with higher flows and velocities and lower proportions of smolts transported.

8. Smolt-to-adult returns were significantly correlated with water particle travel times for wild spring chinook from Marsh Creek, Idaho, as well as for Snake River aggregate spring and summer chinook and steelhead of wild/natural origin.

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Technical Considerations Regarding Survival Estimates: Are We Failing to Capture Critical Details in Relationships Derived from Smolt System Survival Estimates?

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There are a variety of regional modeling efforts that rely on historical estimates of smolt survival in the Snake and Columbia River system. Relationships between survival estimates and flow indices are used to characterize the effects of flow on smolt survival.

In the mid-1980s, regional agencies dealing with mainstem passage issues adopted a subset of the National Marine Fisheries Service (NMFS) system smolt survival estimates from the 1970s to use in the development of a standardized smolt survival/flow relationship that could be used in passage models. Today, those data and/or derived relationships are the foundation for a number of downstream passage models including the NPPC passage models, SNKPASS, PAM, and SPM, as well as the ISP and CRiSP.0 models. Furthermore, it has been suggested that other models that differ mechanistically from the aforementioned models be calibrated to those reservoir mortality estimates.

Historical System Survival Estimates

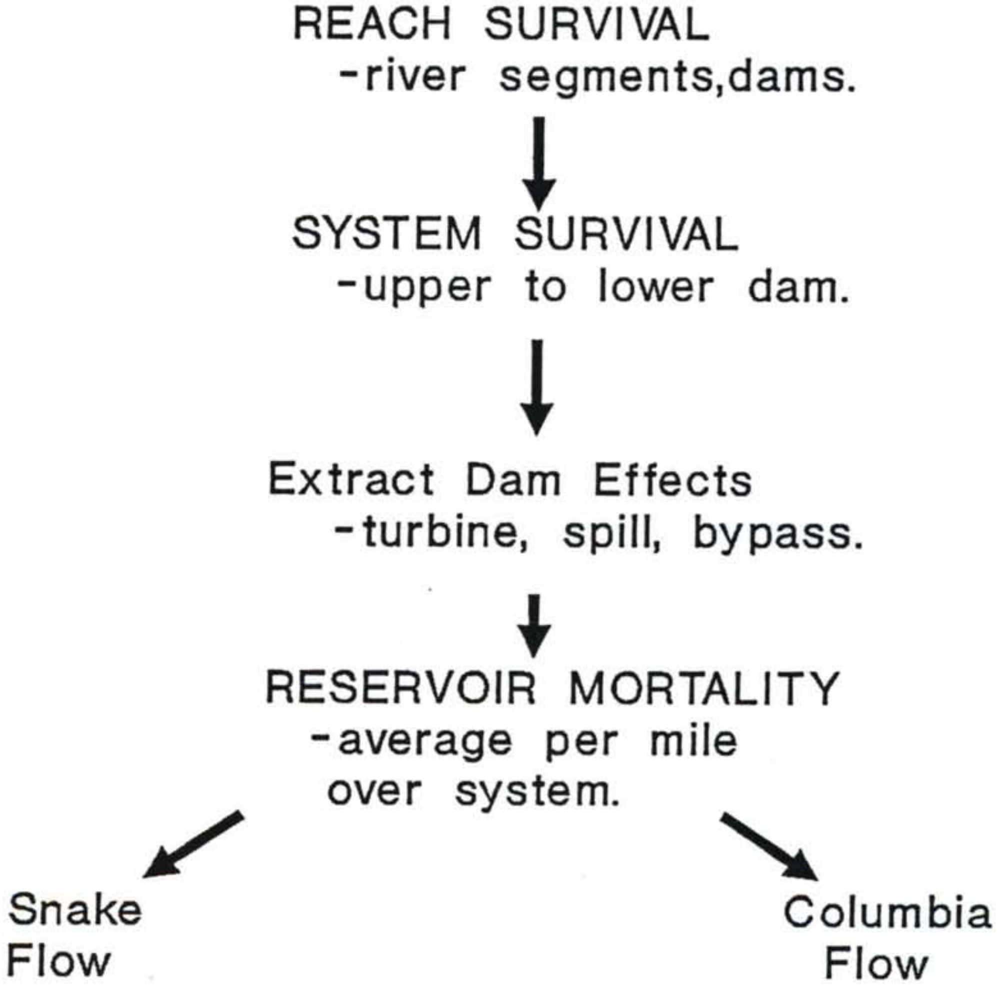
Reservoir mortality estimates are indirect measures that are derived from system survival estimates for yearling chinook and steelhead. The National Marine Fisheries Service calculated and reported such estimates over nearly two decades. The system survival estimates were calculated and reported by NMFS on an annual basis throughout part of the 1960s, most of the 1970s, and early 1980s. Raymond (1979) reported the system survival estimates for the years through 1975, and Sims and Ossiander (1981) reported the estimates for the years 1973 through 1979. Sims et al. (1983) further reported estimates through 1982. Regional fisheries managers adopted a subset of these data from 1970 through 1980, excepting 1971. This data set, often referred to as the Sims and Ossiander data (although it contains estimates for years not reported by them), is commonly used to derive relationships between smolt survival and river discharge volumes. System survival estimates are a measure of the overall smolt survival from the upper dam on the Snake River to a lower Columbia River sampling site, at either John Day Dam, or The Dalles Dam.

Deriving Reservoir Mortality Estimates

Numerous mechanisms affect smolt survival as they traverse the system. Since a key objective has been to quantitatively define the linkage between smolt survival, migration speed, and prevailing river discharge, it was reasoned that mortality incurred solely within the reservoirs should reflect those relationships. Thus, it was necessary to tease systemwide reservoir mortality from overall system mortality estimates.

To accomplish this, analysts have attempted to indirectly estimate, post facto, the dam-related mortality in each year's overall system estimate. The difference between the dam-related mortality and the overall mortality through the system then provided an indirect estimate of reservoir-related mortality (Figure 1). This annual estimate of reservoir mortality is apportioned evenly throughout all reservoirs, and is typically expressed on a per unit mile basis. The collective annual reservoir mortality estimates are then plotted as a function of some flow index during the migration period. This relationship is the key driver for nearly every passage model employed in the region.

Deriving Reservoir Mortality Estimates



REACH SURVIVAL
-river segments,dams.

SYSTEM SURVIVAL
-upper to lower dam.

Extract Dam Effects
-turbine, spill, bypass.

RESERVOIR MORTALITY
-average per mile
over system.

Snake
Flow

Columbia
Flow

FIGURE 1.—Flowchart depicting the derivation of reservoir mortality estimates. Annual estimates of reservoir mortality are plotted as a function of flow indices in either river. The relationships are used as drivers for many regional smolt passage models.

The means by which dam-related mortality is estimated each year is a central issue, because it alone determines how much mortality will be attributed to reservoir processes. Since direct measures of dam mortality were not available at individual dam sites, presumed standard estimates of route-specific passage mortality were applied at each dam site. Depending on the proportion of water spilled, and the estimated fish guiding efficiency, estimates of the proportion of the smolt population passing each of the three routes (turbine, spill, and bypass) were calculated. Standardized estimates of route-specific mortality were applied to those proportions and an indirect systemwide estimate of dam mortality could be produced for each of the ten years making up the relationship.

Location and Magnitude of Smolt Mortality: Details

Do such general estimates of reservoir mortality adequately reflect the location and mechanisms causing smolt mortality? To explore this we need to consider more detailed accounts of smolt loss in the system. There are few instances where this is possible. However, a suite of reach-specific survival estimates are available for yearling chinook in 1973, and can serve as an illustration.

Raymond et al. (1974) reported several reach-specific smolt survival estimates through the Snake/Columbia River during the 1973 smolt migration (Table 1). For yearling chinook, survival from the Whitebird trap site on the Salmon River to the forebay of Little Goose Dam was high, at 90%. In that year, Little Goose was the uppermost dam on the Snake River. At that dam the losses were extremely high; only 50% of fish released in the forebay were estimated to survive to a control release site downstream from the tailrace of that dam. Overall survival from the Little Goose (LGO) forebay to The Dalles dam was estimated at 17%.

Raymond (1979) again reported estimates for 1973, but recalculated system survival in a different manner and reported only 5% survival for yearling chinook, from the LGO forebay to The Dalles (Table 1), rather than the 17% reported previously. However, the same dramatic mortality of 50% estimated previously (Raymond et al. 1974) was reported at LGO Dam. Raymond (1979) provided additional reach estimates that indicated the vast majority of the smolts died en route to Ice Harbor Dam; survival was estimated as 12% from LGO forebay to that site, through two dams and reservoirs, whereas 42% survival was reported for fish passing three dams and reservoirs, from Ice Harbor forebay to The Dalles Dam.

Some unmeasured portion of the mortality estimated at LGO undoubtedly occurred in the forebay, since test fish were released in that location. However, there was direct evidence that severe mortality was incurred at the dam. In the fish collection facility, an average mortality of 15% was observed for unmarked chinook that were held for 48 h (Ebel et al. 1973). Some of the collected fish were transported, but the majority were released to the tailrace. Fish condition was poor; descaling of chinook as observed in the gatewells averaged 14% (Ebel et al. 1973). The combined effects of the newly developed standard travelling screens (STSs) and vertical barrier screens were suspected. Debris accumulation in the bypass system and on the trash racks also damaged smolts, but to what extent is uncertain.

Implications to Reservoir Mortality/Flow Relationships

Since the original NMFS reports indicated that survival was much lower in the Snake than in the Columbia River, apportioning reservoir mortality evenly across the system on a per mile basis appears inadvisable. It overestimates reservoir mortality incurred in the Columbia and underestimates it in the Snake River. Furthermore, the dramatic dam-related effects observed at Little Goose suggest that applying a standard adjustment of lesser magnitude at all dams will overestimate the reservoir morality component. Necessarily, any relationship based on measures of reservoir mortality will also be affected. 1973 is critical in this regard, because it is only one of two low-flow years contained in the regionally standardized survival data set. However, data from every year deserve similar scrutiny. It is not my intention to question only certain annual estimates, but rather to illustrate the types of concerns that underlie every annual estimate.

Yearling Chinook Survival Estimates
1973

Location	Estimate	Derivation Res.Mort.
Trap to LGO Dam	.9	
at LGO Dam	.5	>.85
Thru Snake, LGOf-IH	.12	
Thru Columb., IHf-TD	.42	
Thru System,LGOf-TD	.17 or .05	based on .05
Trap to TD	.05	

Data from Raymond et al.(1974), Raymond(1979)

TABLE 1.—Reach-specific smolt survival estimates reported by investigators at the National Marine Fisheries Service for the year 1973. The far-right column indicates values prescribed in the derivation of the reservoir mortality estimate. The lower case "f" indicates that the reach begins in the forebay of the particular dam.

Results from 1973 clearly indicate that by considering only system survival estimates we have lost important detailed information. This issue is critical with respect to properly characterizing the uncertainty about the reservoir mortality/flow relationship, an endeavor that has yet to be adequately undertaken in any technical forum.

The importance of characterizing the inherent uncertainty of this data set is further underscored when the statistical properties of the survival estimates themselves are considered. Measures of precision or assessments of potential bias are lacking, and only point estimates are reported in any of the numerous research reports.

Over the last few years there have been repeated discussions and debates as to what mathematical function should be fit to the reservoir mortality/flow relationship, e.g. quadratic, exponential, or linear-based broken stick. I would vigorously argue that fundamental concerns regarding the uncertainty of existing reservoir mortality estimates overwhelm all other concerns and make such considerations inconsequential.

Apart from these concerns, there is another fundamental limitation with applying this historical data to the existing river system: the data were acquired many years ago under very different physical and biological conditions. Physical structures at dams and facility operations have changed. Bypasses have been installed and regularly redesigned. Spill and water management programs have evolved and been implemented.

Biological systems have changed, too. The complement of hatchery and wild salmonids has changed over the years. If they have inherently different vitality, this will be reflected in survival estimates. Also, the population structure of predatory fish has probably changed over the years, but how, and to what extent is unknown. This in itself has obvious implications to reservoir mortality dynamics, yet we cannot quantify it. Thus, even if the historical data were statistically sound, its relevance in today's ecosystem is questionable. We desperately need improved smolt survival estimates under current conditions.

Until such estimates are available we are forced to employ existing analytical models. However, there are obvious problems in relying only on models that are driven by these generalized indices of reservoir mortality. Efforts should begin immediately to properly characterize the inherent uncertainty in such models. Furthermore, it is imperative that mechanistically diverse models be used in concert to evaluate smolt survival dynamics, particularly for any comprehensive evaluation. The merits of this approach are recognized by some regional groups, and it is being applied in certain analytical forums in the region. However, some parties have argued that mechanistically different models all be calibrated to extant reservoir mortality estimates. I trust the issues I have illustrated here would dissuade analysts from pursuing that strategy.

Summary

1. Smolt reservoir mortality estimates are general measures of smolt performance that are derived from generalized historical indices of system survival.

2. These measures do not accurately identify the location or magnitude of smolt loss as smolt traverse the system.

3. More detailed reach-specific smolt survival estimates from 1973 indicate that massive losses were associated with passage at the uppermost project that year. The derived reservoir mortality estimate for that year mistakenly apportions that mortality throughout downstream reservoirs. Similar problems may exist for other years, and warrant scrutiny.

4. By relying on such indirect measures of reservoir mortality we have lost important details regarding the

location and magnitude of loss, and we may be mischaracterizing the mechanisms causing mortality. It is imperative for analysts to properly characterize the uncertainty regarding these estimates as well as any relationships constructed from them, because these estimates are key drivers in many models currently in use throughout the region.

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Modeling Smolt Transportation in the Columbia River: Management Implications of Using the Passage Analysis Model (PAM)

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Purpose

Transporting juvenile salmon and steelhead by barge or truck has been used as a means of increasing downstream survival in the Columbia River for many years. Transportation research began in the 1970s, when activities focused on developing techniques. Transportation became operational in 1981 (Park, 1985), and has been used extensively since then.

This paper will discuss a model for smolt transportation and suggest how a model can be used to manage transportation and plan future activities. The implications of the transportation model will by explored bu using a generalized model of downstream smolt survival. The goal is to achieve a logical model of smolt transportation that is consistent with empirical data.

A Generalized Transportation Model

Transportation management is presently limited by a lack of data on the benefits of transportation over a range of conditions. Indeed, a major purpose of a model in this case is to help us make rational hypotheses about how transport might affect survival under conditions for which we have no observation of transport benefits.

During the 1970s, the National Marine Fisheries Service (NMFS) compared the benefits of various transport vehicles, mediums, and techniques. These studies, summarized by Park (1985), were useful in the development of transportation and for establishing a general range of benefits. More recently, Matthews et al. (1991) measured the benefits of transport under 1986 passage conditions. The results from this study were used to calibrate the model discussed here.

Most techniques to improve fish survival, such as spills, bypasses, flows, and others, have been measured by their effect on downstream fish survival only, not by their effect on adult returns. The effect of any of these techniques on survival after fish cross Bonneville Dam are generally unknown. Transportation is an exception. From the very beginning, transportation effects have been measured as the ratio in smolt-to-adult survival rate (SAR) between fish that were transported and those that were not transported in the same year. This ratio is termed the transport benefit ratio or TBR. For two groups of similar fish in a single out-migration year, the TBR is expressed as follows:

$$TBR = \frac{\text{SAR for transported group}}{\text{SAR for non-transported group}}$$

The SAR in this case is measured from the point where the nontransported control group was returned to the river after marking.

This simple expression suggests two general models about how transport benefits might vary:

Model 1: The TBR could be constant. Because the SAR for nontransported fish is known to vary with conditions, a constant TBR says that the SAR for transported fish also increases as in-river conditions improve.

Model 2: The SARs could vary independently and the TBR could change. Because survival of nontransported fish increases with flow or improvements in other passage conditions, this would imply that the survival of transported fish does not parallel the survival of nontransported fish.

The summary by Park (1985) provides estimates of TBR over several years. The broad range of results dispels any notion of a constant TBR. Data on steelhead benefits is the most complete and suggests an inverse relationship between flow and TBR (Figure 1). These facts support model 2.

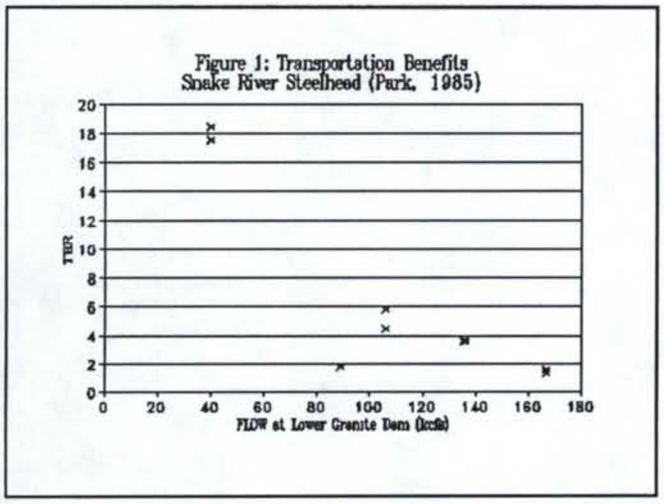
Figure 1: Transportation Benefits
Snake River Steelhead (Park, 1985)

If the TBR declines as flow and the survival of nontransported fish increases, then the SAR of transported fish once they are in the vehicle must be relatively constant compared to the survival of nontransported fish outside the vehicle. (The survival of transported fish up to the point of collection would still be affected by in-river conditions.) The TBR would then be inversely proportional to the survival of nontransported fish. As in-river survival increases, because of better flow, for example, the benefits of transport would decrease as shown in Figure 1. Because the survival rate within a year is greater for fish migrating from McNary Dam than from Lower Granite Dam, it also suggests that the TBR would be greatest from Lower Granite Dam and least from McNary Dam.

While the SAR of fish in the transport vehicle may not be affected by conditions outside the barge, it is probably a simplification to say that the survival is constant between years. For example, at very low flows, fish might enter the transport vehicle in very poor condition relative to their condition at a higher flow. This would decrease the survival of the transported fish. The survival of fish in the transport vehicle is probably affected to a much smaller degree by outside conditions than is the survival of fish migrating through the system. Information on how the survival of transported fish is affected by conditions before the point of collection is extremely limited, however. This forces us at present either to assume that the survival of transported fish is constant, as described above, or to arbitrarily assume different TBRs for different conditions. The first option is advocated here since it provides a logical basis for assumptions and lends itself to creating testable hypotheses[1]

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[1] Work is underway by the author and others to derive a relation between the SAR of transported fish and inriver conditions prior to collection.

Implications of the Model to Transportation Management

The use of an explicit model such as the one described above can result in better management. The basis for decisions can be described and maximum use can be made of limited data. Most importantly, it can suggest important avenues for research. For the sake of brevity, in the analysis below, only one model and assumption set is used. However, it should be emphasized that a major benefit of this approach is the opportunity to explore the implications to management of alternative points of view. Natural variation has important implications for management and could be incorporated as well.

The implications of Model 2 on present transportation management were explored using the Passage Analysis Model (PAM; NPPC 1992). PAM is a spreadsheet model of fish passage in the Columbia River. It is based on the Sims and Ossiander (1981) estimates of system survival and reduction of these estimates to mortality per mile (McConnaha, 1989). An exponential fit to these data derived by Petrosky and Weber (1990) was used to estimate mortality as a function of flow and reservoir elevation.

The transportation model described above was calibrated by use of the observations by Matthews et al. (1990). Under 1986 passage conditions, they reported a 1.6:1 TBR for spring chinook from the Little Goose tailrace. For this exercise, the survival of nontransported fish under 1986 conditions from this point was estimated using PAM. The survival for transported fish was set at 1.6 times this rate. This would result in a ratio in the SAR between transported and nontransported fish of 1.6:1 for 1986 conditions. For all subsequent analysis, transport survival was fixed at this rate while the survival rate of nontransported fish varied with passage conditions. As a result, the TBR varied in response to changes in passage conditions relative to those in 1986[2].

PAM was used to examine the implications of the transport model on two aspects of transportation management.

1. TBR as a function of flow: implications for transport triggers.—Annual transportation policy is presently set by an interagency committee called the Fish Transportation Oversight Team, or FTOT. This group has established transport flow triggers that set the conditions under which transportation should occur (COE, 1992). At Lower Granite Dam, all spring chinook collected in the bypass system are transported regardless of flow. At Little Goose Dam, spring chinook in the bypass system are returned to the river at flows over 100 kcfs, while at McNary Dam collected fish are returned to the river at flows over 220 kcfs. This policy was examined under the model described above.

Under Model 2, the TBR will decrease as the survival of nontransported fish increases. Because of this, the TBR at each project decreases as flow increases. The function mirrors the exponential shape of the reservoir survival function (Figure 2). The TBR can also drop below one at all three projects. Presumably, managers desire to transport fish only when the TBR is greater than one.

Using this rationale, the benefits of transportation as predicted by Model 2 were compared to the implied benefits as stated by the FTOT guidelines. This was done by using PAM to predict the number of times that the TBR would be greater than one for spring chinook at each collector project over the 50-year record of runoff from 1929 to 1978. This was compared to the number of times that transport would occur at the collector projects under the FTOT guidelines given the same flows:

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[2] Note that the implication of this procedure is that transported fish do not survive as well as non-transported fish past the point of release below Bonneville Dam. However, in 1986, at least, the increase in passage survival of the transported group relative to the control group was sufficient to produce a 60% better SAR in the transported group.

Number of times TBR would fall below 1.0

Project	PAM Estimated	FTOT
Lower Granite	5 of 50	0 of 50
Little Goose	6 of 50	22 of 50
McNary	31 of 50	37 of 50

These results suggest that Model 2 at least implicitly underlies the FTOT guidelines. The fit between the model predictions and what would occur under the FTOT guidelines is very close for Lower Granite and McNary dams. The model does, however, suggest a higher flow trigger at Little Goose Dam.

More than to suggest a change in the FTOT guidelines, these results are presented to illustrate a method of arriving at management guidelines given a very limited information base. It also suggests a structure for transportation research to investigate the change in TBR with in-river passage conditions.

Figure 2a: ESTIMATED TRANSPORT BENEFITS
Spring Chinook: 1986 LGS BASE

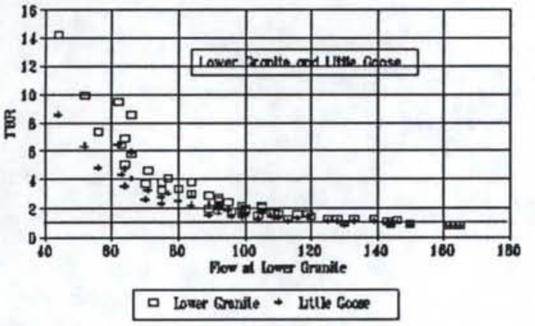
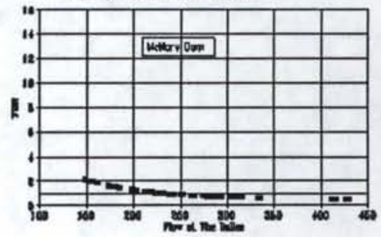


Figure 2b: ESTIMATED TRANSPORT BENEFITS
Spring Chinook: 1986 LGS BASE



2. *The role of transportation in the future*—Assuming that transportation benefits vary inversely with in-river passage conditions, transportation should have a declining role in the future as measures are taken to improve passage conditions. This is illustrated by comparing the overall benefits of transportation under existing passage conditions and under improved conditions.

PAM was used to simulate survival for all spring chinook migrants, including transported and nontransported fish, and for those fish that migrated through all eight projects. Under existing conditions, transportation improves survival over the alternative of in-river passage in 45 of 50 flow years (Figure 3). Survival without transportation is greater once flows exceed about 135 kcfs in the Snake River and 330 kcfs in the Columbia River.

The point where survival without transport exceeds survival with transport will shift as in-river conditions improve. Figure 4 illustrates the same situation after screens were installed at all projects and extended length screens were installed at all collector projects, and when predator removal resulted in a 25% reduction in the rate of mortality in the reservoirs. Transportation under these conditions improves survival in 34 of 50 years. Survival without transport is greater when flow exceeds 110 kcfs in the Snake River and 275 kcfs in the Columbia River. From McNary Dam, transportation provides a benefit in only 4 of 50 years.

If transport benefits decline in the future as this analysis suggests, this projected decline should be reflected in present decisions on the development of passage improvement measures. For example, perhaps funds spent to improve transportation facilities at McNary Dam are better spent elsewhere. However, it is not the intent of this brief analysis to suggest directions. Rather, the purpose is to illustrate how a simple model can be used to bring the existing, limited information base to bear on important management problems. It is essential, however, that the limitations of the data be recognized and that improved information is developed to support improved management.

Conclusions

1. A simple model of smolt transportation was described, stating that (a) transportation benefits decline as in-river passage conditions improve; and (b) transportation benefits should be greatest from Lower Granite Dam and least from McNary Dam.

2. This model was applied to two management questions to illustrate its use and implications.

3. The model appears to underlie present management guidelines for transportation while suggesting a modification in the transportation flow trigger at Little Goose Dam.

4. The model suggests that the use of transportation should decline as measures are taken to increase in-river passage survival.

5. The use of this type of analysis makes it possible to bring limited information to bear on management problems and to design experiments yielding information that improves management.

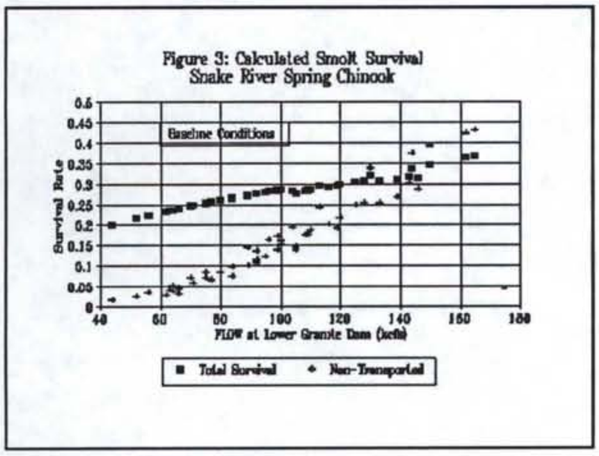


Figure 3: Calculated Smolt Survival
Snake River Spring Chinook

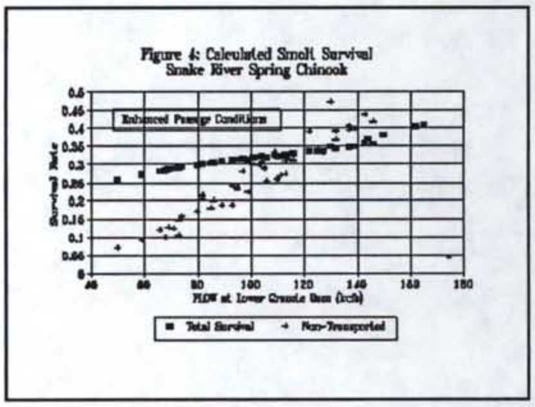


Figure 4: Calculated Smolt Survival
Snake River Spring Chinook

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Discussion on "Factors Affecting Migration Rates and Survival through Reservoirs"

Facilitator: JOHN WILLIAMS, *National Marine Fisheries Service*

Question: I would like to ask Charlie Petrosky about his slide that showed an increase in the numbers of chinook transported from 1982 up to 1988 or 1989 and an increase in adult returns up to 1987 and then a drop-off in later years. Are you aware of the fact that hatchery production doubled in 1987 and how much of a factor do you think that is?

Answer: Well, undoubtedly a greater hatchery contribution is going to reduce that return rate but you see the same thing occurring in the period preceding that, the 1982 to 1984 flow years.

Question: I've got a question for Charlie with respect to that. Charlie, were the transport numbers that you displayed total numbers transported or were they adjusted to reflect a percentage of the total number of the population that was transported?

Answer: I used Park's 1985 paper, which took us through 1983 or 1984, and for the later years I used his fish passage center data. Those are total numbers. It is very obvious that by about '80 or '81, the wild population had just about bottomed out. The 1982 out-migration encountered reasonably good flows and we got a very good return from them and from the '83 and '84 out-migrants.

Question: Charlie, 1985 was the lowest flow year of that period, yet we saw good adult returns from the 1985 out-migration.

Answer: Yes, we did.

Questioner: Yet, 50-60 percent of the fish were transported that year.

Answer: Yes, I agree. Those smolts did have a good return. We also started out that smolt migration year with reasonably good flows and then it shut down to 80 kcfs or lower. It was an unusual pattern. We didn't have PIT tags in the system to know if large numbers of out-migrants from the Middle Fork went out early with the higher flows.

Question: There seems to be a real reliance on a little bit of data and a lot of controversy on whether or not you can get better survival estimates or whether you can get survival estimates at all. Is there something better coming?

Answer: Yes, I think there is an opportunity. You probably recognize that I'm working with Doble and Skowski and Hoff at the University of Washington on this issue. They have developed a protocol that should let us estimate smolt survival from release sites upstream from the dam complex to the last PIT tag recapture site in the system. Within the next year or so we should be able to test this protocol. We can't really evaluate anything unless we can improve survival estimates.

Question: One of the correlations you showed in your presentation was the smolt to adult return ratio as a function of the water particle travel time. Now, it occurs to me that over this 20-year time frame one of the major components that affected that decrease in water particle time was the emplacement of dams in the system. Now the dams kill fish independent of any flow effects. How do you factor that out of that relationship? It seems you have two variables there that are potentially affecting survival.

Answer: Yes, there are more than two variables involved. Under the standard assumptions of Fish

Guidance Efficiencies (FGE) with no spill, and assuming 15 percent mortality going through the turbines, that results in an estimate of about 40 percent survival through eight dams, assuming no transport. That can't account for the range of smolt to adult returns over the years. What we really need to do is to calibrate the model in a way similar to what we did with the fall chinook model with Howard Shaller and Tom Cooney. We are trying to develop a similar model for spring chinook that calibrates some of the Snake River stocks with, for example, a Deschute's stock that doesn't go through the dams. In that way, we can explain the difference in the residuals due to location in the system. That kind of empirical analysis will get us into better ballpark estimates of the amount of mortality due to variable conditions from year to year. I think then we can start to play the "what if" games with our assumptions.

Question: The point is that right now in that correlation there are at least two critical variables that are affecting your survival response, the mortality just within the hydro complex itself as affected by the speed of the water, and the turbine mortality that was incurred while turbines were coming on line through the '60s and '70s.

Answer: Yes, that's right.

Question: I have a question for the modelers. It has to do with decisions that are being made currently or will be made in the near future about fish passage problems, spill, and so on. These models that we've talked about today may be used in these decisions. Yet, we've seen today that there are uncertainties about the underlying assumptions of some of these models, which seem to be based largely upon the Sims and Ossiander data, particularly about the two data points (1973, 1977) that seem to be driving that relationship. In addition, there are suggestions that other variables that aren't considered in the models can be very important. Should we be using these models for decision making at the present time?

Answer: The best thing that you can hope for is that the model, after it's understood, will be fairly invisible to the process and will allow the decision makers to base their decisions on the biology. In the case of the two data points you mentioned, I would be concerned about taking the approach that said that our models suggest that those aren't real points and that we should arrange the empirical data to fit our models. I don't see any problem presenting the data as they are and letting the decision makers make their decisions based on that.

Question: That's a good answer, but I didn't mean to criticize the models or say that we don't need models or they aren't useful. But there may be a point at which there is so much uncertainty about the parameters that go into the models that the output simply is not reliable enough to make decisions upon. Are we at that point now? Or are we at a point where we can really believe what's coming out of these models and can we really base decisions on them? Or should we say, we've got to go back to the drawing board and wait until studies are done to settle some of these sorts of really disparate results we have presented today that give almost diametrically different views of the same problem.

Answer: If I thought there were really diametrically opposed views, then I don't think that that would be a good candidate for a modeling process. I think that the things that we are talking about are fairly well established. There may be some arguments over certain data points or the treatment of the data but I think the fundamental relationships are reasonably well established.

Comment from Floor: Just a second. The situation at the collection facilities now is very different from the way it was in the 1970s. There is no question that we didn't have good results from transportation back in the 1970s. I was out at the collection systems then and I can tell you the fish were in awful, terrible shape. In 1977 our post-marking, 48-hour delayed mortality was 30 percent and ranged up to 70 percent. There were dead fish all over and massive debris problems. We have seen low flows and conditions in the last five years that may not be quite as bad as '77, but are pretty close. Despite that, the wild fish are actually holding their own pretty well right now. If this five-year extended drought had occurred in the late '70s, the Snake River chinook salmon runs would be in the same shape as the Snake River sockeye runs.

Comment from Panel: Models are one of three ways we have of making decisions—we've got the observations, we have our intuition, and we have these models. We need to look at all of those and if we can get agreement in these three realms, then maybe we can feel more confident about our decisions. Models can project ahead in the future and give us some idea of what we might expect. If we have people with different viewpoints doing the modeling process, we can look for uncertainty and find out where we agree and disagree. That is valuable. We won't be able to really confirm whether the models "work" for 30-35 years until we get enough adult returns for statistical analysis. But we have to make decisions before the next three decades and models are one of the three critical elements.

Another issue modelers can be involved in—and we are not really doing our job on this—is to bring out other factors to look at that might be significant. We are talking a lot about this flow-survival relationship, but we haven't really dealt with issues such as fish condition, the fact that we might be overstocking some of these reservoirs, etc. We are not modeling the impacts of harvest. As long as we keep focusing just on the flow-survival relationship, we as modelers are doing a disservice to the community. I would like to see us continue and try to resolve the flow-survival relationship, but I think we need to also look at some of these other issues that people are bringing up in a quantitative way.

Comment from Panel: I object philosophically to the idea of model-building as being a process distinct from what everybody else is doing. I think everybody in this room right now is a modeler—whether you like it or not—because when you go out and you look at any kind of variable and you try to relate it to anything—which is all what we are trying to do—you are a modeler. So what we talked about up here today is not really anything esoteric or anything distinct. It's just that we took a whole lot of the research information that has been generated over the years and put it together and put it on the table and said, "What the hell does this incredible mess of information say about the process?" And I think that if as a scientific community you come up with the conclusion that models aren't going to work because the data's lousy, we are basically telling the decision maker that science really has very little to offer. And they do have to make decisions, with us or without us. As a professional community what we can do is to suggest ways of using models based on the information we have—and suggest ways to the decision maker that certain things are sensitive, certain things are not. A great deal of what we argue about in here, I think, if we really looked at it critically, on a sensitivity kind of analysis, we would find to be a pointless argument. And frankly much of the disagreement about the Sims and Ossiander data is not critical to rebuilding upriver salmon runs. You can put the pieces together and show some general kinds of strategies that will work. What we have to do is recommend to those decision makers ways in which we can deal with the areas where there is honest scientific disagreement or unknowns, and focus our efforts on those kinds of things. That's not really a modeling problem so much as it is just a way we as a profession conduct ourselves.

Hopefully, models are not taken any more seriously than the observational information that most of the research in this room is generating. Models can often give you the viewpoint that there are simple solutions. That's why the professional community has a responsibility to point out the uncertainties as well as the things we do know. After 80 years of research on the Columbia River we do know a few things and there are some things we don't know. A model can show the consequences of uncertainty. And the responsibility we have, I think, is to point out that uncertainty and to try to direct the process to answer those things. But not to simply throw the whole thing out and say, gosh, there is so much uncertainty that we don't know this and we don't know that and so everybody goes in the back room and puts the visors on and lights their cigars and goes at it. Then science, I think, has failed.

Comment from Floor: I would like to see some of the other modelers continue with Chip's discussion on what models are and how they should be used. The most dangerous thing about models is that the decision maker who doesn't know anything about them or how they were put together is going to use this black box to make some decisions. I think most of the modelers would agree that the power of models is to go back and look at what we know about the inputs and try to straighten out the information that we are going to use for our decision making. The definition of a model I like the best is "a set of lies that helps us explain the truth."

Comment from Panel: There is an educational aspect to models. If we can get the decision makers to use the models and understand the complexities and the nature of them they can develop some intuition into what happens when we put all our collective data together and see what the outcomes are in terms of sensitivity. Where should we be agreeing and disagreeing? Where do we not know something that may be important and where can we look for the answer? I always have a problem when people say the model is leading the data; that's bad. I think the model should be out there helping to guide what types of data we are taking. But another reason for a model, I suppose, is to predict the future. That's the one people are most worried about.

Comment from Panel: It is real important for us, especially those who develop and use models, to maintain the clear distinction between a model that is used in the management arena and one that is used in research planning. There is a big distinction. People frequently fail to make that distinction and as a result a lot of "what if" guessing type models make it into the management arena. I think that's a mistake.

Comment from Floor: I worked on the Galloway model for the Corps of Engineers and we have used it for justifying several of the juvenile fish bypass systems. For example, we justified the Little Goose juvenile fish bypass, a $9 million project, on an improvement of about 0.6 percent in survival of juvenile fish going downstream. So that was a real application for a model.

I also have a question. Chip, you said in your discussion of your model that you were making the assumption that juvenile fish going down through the system and juvenile fish that were transported below Bonneville Dam survived at the same rate after Bonneville. How can you come to an assumption like that when it only takes one look into a barge to see that there are sick fish and weak fish being loaded on with the well fish and the strong fish? I think there are people in this room who would say that going down through the hydroelectric system weeds out the sick and the weak fish so you obviously have to have different survival rates for transported and migrating fish.

Answer: I did say that, but I also qualified it. What we do is to wrap up all the error into the survival rate assigned to transported fish. The survival rate of fish from the point of collection transport until the time the adults come back is actually a product of the survival rate during transportation times the survival rate after that, in the estuary and ocean. Well, if you roll up the difference between the transported and nontransported groups into the juvenile passage survival rate, the product comes out the same. The survival rate during barge transport is apparently high, probably not too far from 100%. Say that a good estimate of the survival rate of those you didn't transport was 25 percent—that's not a bad rule of thumb—that would mean you would get a transport benefit ratio of 4 to 1. Well, point of fact, we don't usually see a 4 to 1 benefit ratio, which means that, just as you said, the transported fish had to survive at a lesser rate than the nontransported fish below Bonneville Dam. So if the transport benefit ratio for a given year was estimated at say, 1.6 to 1, I would figure out the survival rate of nontransported fish from Goose to below Bonneville and then fix the transport survival rate at 1.6 times that. That rolls in all of the error in that assumption into the transport survival rate and standardizes the two in terms of the transport benefit ratio.

Question: Today we have been talking primarily about getting fish from upstream areas down to the first dam. What can we agree on in terms of what we need to do to improve the survival of the fish down to the first dam?

Answer: I think we are probably going to have to wait until tomorrow to address that because some of the mechanisms that are affecting survival—such as disease—are going to be treated in tomorrow's session. I don't know if we are going to get into the integrity of the upstream ecosystem, but that has to have some bearing on the survival that we see to the first hydro project, apart from flow considerations or anything else. We need those issues out on the table to fold into this discussion.

Question: Do you think some of these factors could be affecting survival of wild fish out of the Middle Fork of the Salmon before they get to Lower Granite Dam?

Answer: Well, I think they could well be, but we don't have much information.

Answer: One thing we do know is that we definitely need improved velocity conditions. As for the Middle Fork of the Salmon, I have been here since the late '70s and talked with many people who were here from the mid '50s and I see no reason to believe that things have changed to any measurable degree in the wilderness area—definitely not to any measurable degree. We don't have that piece of information. On the other hand, we definitely have seen some changes in the flow conditions with the building of the dams. There are a number of variables associated with the fish passage at the dams and through the reservoirs. That's where most of the changes have occurred.

Comment from Floor: I want to be clear that I'm not suggesting that we don't need some sort of a minimal velocity regime, upstream as well as down through the hydro complex, but I don't think we have done a very good job in quantifying what the response of the fish is to water particle travel time because we have neglected another important variable, that of smolt development. Two processes are involved here—the initiation of migration in addition to the actual migration event. When you are measuring fish travel times, and you have both of those processes folded into the response you're looking at, you're not getting a true calibration of the effects of flow on migrants, because you have that initiation phase wrapped up in it. Until you can separate those effects you are not going to get a true indication of how much effect flow is having on travel time.

Another point concerns the location of losses of hatchery smolts. When I look at Ed Beuttner's data on minimal survival estimates from the trap at Lewiston to Lower Granite and Little Goose dams, and then I look at the loss that's occurring from McCall and Sawtooth and so forth to those dams, it appears that there is considerable loss occurring prior to arrival at the trap site. That's above the effects of impoundment—that's basically a free-flowing stretch of river. There are only so many processes that you can identify that fish can be dying from in that complex. It may be either carrying capacity, with possible interaction between hatchery and wild fish, or disease problems. We don't have a handle on these possibilities, so what can you say?

Comment from Floor: Wild fish coming out of the system should be fully smolted by the time they hit the hydro complexes, and they are the fastest individuals moving through that complex. I suspect that if you look at Beeman's curve that those fish are going to lie on the lowermost curve that he plotted. He had four curves that varied with ATPase level from low smolt development to high smolt development and each one of those was a different response curve.

Question: If that's true, why are Middle Fork stocks at 20 percent of what they used to be?

Answer: That's the point. If they are moving swiftly through the system and they get through at high flows or low flows, is there any other process that's affecting these fish? I'm suggesting that there is a whole bunch of possibilities we haven't focused on in the last 20 to 30 years. We have completely turned the ecosystem upside down. Now we want to consider this ecosystem to be a pipe and we're plumbers and we are going to fix the problem by putting more water through it and that's going to solve everything. I just don't buy it.

Comment from Floor: If you look at Bear Valley Creek where we do a lot of tagging in the summer, there are cattle being driven all up and down through that creek. If you compare that creek with some other more "pristine" creek, the habitat is entirely different. In some creeks the water is crystal clear and there are no sediments on the bottom, but in several of the streams in the Middle Fork drainage, you see a lot of sediments and the habitat is being destroyed by overgrazing or just running the cattle through the creeks. If you drive 800 head of cattle through a creek, you're not helping that creek out any. And if you are doing that two or three times a week, which this one rancher happened to be doing while we were up there, you see that there is a problem. We need to look at what's happening in these habitats and not just say well, 30 percent of our habitats are still pristine.

Question: We have known since the late '70s early and '80s that a very large percentage of the hatchery fish haven't been arriving at Lower Granite Dam. This isn't anything new. It doesn't seem to be a factor of flow. Look at the last three years: the numbers of fish adjusted for hatchery releases that have been collected at Granite and Goose dams are virtually identical for the three years under three very different early April flows.

How about changes in survival through the hydroelectric complex? The '82-'86 out-migrations more than tripled the population of wild salmon in the Middle Fork. There is no question that the 1970s were the terrible '70s. I don't know why we should be surprised that we may have better down-river survival now than we had then, because there was absolutely nothing going on to protect fish at that time. The agencies lobbied very hard for spill programs at Lower Monumental and Ice Harbor dams for salvage operations, for running turbines at maximum efficiency, for cleaning debris off the trash racks, and what not. And we still don't think we've done any good and it's still the '70's? Why did we ask for all that?

Answer: I'll answer that. You're right that the improved maintenance of the trash racks and other improvements have undoubtedly helped. But again, the majority of that mortality seems to be reservoir mortality. There is really not much other way to account for it. I think Tom Bergerand's example shows the relationship between smoltification and flows. If they're ready to move they're going to have a tendency to move, but at that same readiness, they're going to move faster at higher flows.

Comment from Panel: If I asked for a show of hands, does anybody in here really think that flow isn't good for fish or that flow isn't a factor in fish survival? Right now the way the debate has divided us, you either are a flow person or you're not a flow person. We have to improve survival and I don't think anybody would say that putting all of those hydro projects in and slowing the water down has not affected fish survival in some fashion; It's obviously part of the equation. But you've got to increase survival however you can. Flow's part of the equation; habitat's also part of the equation. Right now everybody is trying to grab for a simple solution—that it's either transportation, or it's flow, or it's hatcheries, or it's Taiwanese gill netters, or it's something else. It's usually the other guy, of course. But there's not one solution to this, and I keep hearing this debate on whether you salute the Sims and Ossiander approach or you don't salute it. I think it is really destructive and I don't think it's helping the decision-making process at all.

Comment from Panel: I agree. I don't think it is a problem with a single cause. Very few things are. With regard to one thing that those of us who have done life cycle simulations can agree upon, when we put all the things in the models that have been proposed so far—flow is probably one of the most sure things, predator removal, the effects of supplementation, certainly habitat is pretty certain—if you plug all that into a life cycle model, I think we can agree that the corrective measures aren't going to restore fish runs. It may keep them from declining and in some cases might have some slight rebuilding, but by and large what has been proposed so far is not the answer.

Question: What proposed measures are you referring to?

Answer: Primarily those proposed by the Power Council. That has been about the main thing put on the table, which has been like kind of a centerpiece. On the agencies' and tribes' parts we have not proposed anything of our own—except for the flow proposal which has been criticized, and probably rightfully so, for being somewhat unrealistic. If there is anyone who would like to disagree with me go ahead, but I believe that is really not going to do the trick. More specifically, we have proposed some rather optimistic things like a reduction in predator mortality of 50 percent. I think that's a space shot myself. Other things have been an increase in the length of screens, with a doubling in FGEs (fish guidance efficiencies) due to that. Preliminary indications are that it is not going to double the FGEs, at least not in the case of fall chinook. The two things we are really hanging a lot on are supplementation and predator removal, but these are two untried weapons at this stage of the game.

Question: One thing that came up earlier in the modeling discussion was that we didn't want the decision makers to oversimplify what we're telling them through these models, but I think that's exactly what's happening. And I'm even hearing some of it from the panel in using flow and velocity interchangeably. These models were all based on flows, even your water particle travel time work was based on flows and not on velocities. But what I'm hearing from decision makers is we might be able to achieve what we need to with even less water if we can get the velocities through a drawdown situation. Another point I want to make is that we seem to have in effect accepted poor survival rates and attempted swamp the system with more fish to overload those low survival rates. This may be part of the problem rather than the solution.

Comment from Panel: I agree with your remark on velocity and flows. They're related, but they're not interchangeable.

Question: Everyone's questioned the data points for 1973 and 1977 when survival estimates were low for the out-migrating smolt compared to those released in high-flow years. What was the adult return from those two years?

Answer: The adult return from 1977 was bad enough to put us in an ESA (Endangered Species Act) situation; 1973 was also pretty dismal, although not quite as bad.

Comment from Floor: Again I want to emphasize how drastically conditions at the collection systems in 1973 and 1977 differed from present conditions. In 1977 the fish were not moving into the collection systems at all; the Lower Granite forebay was filling up with fish. We went out and purse seined in the forebay in 1977 just above this huge debris pile that had been there for three years and found that the fish in the forebay were descaled. You had to go up the reservoir about five miles before you could find fish that were not descaled. After the fish entered the system, our post-handling delayed mortality averaged 30 percent and ranged up to 70 percent in 48 hours. Now, today, even though we are handling about 95 percent hatchery fish, the mortality of chinook salmon is 0.8 percent on average—lower than for steelhead. The systems are totally different than they were in 1977. We would plug a six-inch loading line to the barge completely solid with debris—solid, with twenty feet of head on it, and that was after we tried to clean out as much debris by hand as we possibly could. It was an absolute nightmare. We would work 72 hours straight, without sleeping, trying to keep things together. There were dead fish everywhere. We were hollering and screaming and nobody was listening. You are seeing flow conditions now that are close to 1977 but we're not seeing the massive problem that we saw then. There is no question that the 1977 out-migration was decimated. There were only 38 redds counted in the Middle Fork in 1980. But there's a big difference now. We're not seeing that huge crash now that we saw then.

Comment from Panel: I would beg to disagree. It might not be quite as huge, but it's proportionately huge. The flow conditions in 1977 were the worst on record. We've approached it recently and we have approached that same bottoming out that we saw following the 1977 poor flow conditions.

Reply from Floor: When, where?

Reply from Panel: In many of the Middle Fork Salmon tributaries. Parr densities dropped about four- or fivefold from 1989 to 1990-91.

Reply from Floor: Yet, this last summer's redd count in the Middle Fork was about 250-300 redds, something like that. In 1980 it was 38. And they're in an extended drought up there. In many areas the streams only have half of the water in them that they used to have.

Reply from Panel: It is still not much of a buffer.

Reply from Floor: I agree with that. Another thing I would like to ask is why is the South Fork not doing as badly right now as the Middle Fork?

Reply from Panel: The South Fork seems to be, for some reason, a little more buffered, so that recruitment doesn't respond as strongly to either a good out-migration flow condition or a really low flow condition out-migration.

Reply from Panel: Summer smolts out-migrate very early from that system—in April, when flows are generally the lowest. On the other hand, Middle Fork smolts come out late with the thundering herd.

Comment: When you look at Russ Keifer's information from the upper Salmon River, which is, with respect to elevation and stock characteristics, probably most like the Middle Fork, there's a large proportion of out-migrants that arrive at Granite in the early group. Is that right?

Answer: It's hard to compare them because, you know, we just tag what we can capture at the traps and they're not really comparable, but the fall out-migration does contribute a large percentage of the fish being detected down at the dams, when compared to Crooked River. Fall out-migration from high-elevation streams is very important, and they seem to arrive in that early period with the hatchery fish.

Comment: We seem to be running out of controversy, so I will try to generate a little bit. Back in the late 1950s and 1960s when the Lower Snake River projects were being designed and constructed, the fishery agencies looked at building hatcheries as the solution to the problem. Since then we have built or reconstructed eleven hatcheries that are producing somewhere in the neighborhood of 15-20 million fish and they haven't solved the problem. Now we're saying that augmented flow is the solution to the problem. We're overlooking two very critical factors. One is what's happening to the natural spawning areas and rearing areas and the other is what's happening with the harvest. You can't solve all of the problems by fixing the problems at the dams. If you don't fix the harvest, and don't fix the spawning and rearing habitats, the fish will be gone.

Reply: Well, I can give you the tribal perspective on that. They have seen their harvest drop from 5,000,000 down to 100,000. If you're saying that harvest is a problem, perhaps, but politically I don't think it's feasible. As far as habitat is concerned, I don't think anyone is going to disagree with the concept that the habitat is in bad shape for a bunch of reasons. I would say there are more than two other problem areas besides simply flow.

Comment from Panel: I have another point about habitat conditions. Bear Valley is being hit pretty hard by cattle. If you go back to the early Fish and Wildlife surveys and compare them to more recent surveys, sediment seems to have increased in that stream and the pool volumes seem to have decreased. But right next to that is Sulfur Creek. It has a couple of little back country ranches on it, a few horses graze there, but primarily it is a pristine stream. Nevertheless, we see the same low escapements, low production of juveniles there as in Bear Valley, but occurring in a perfectly pristine stream. That says to me that we can do everything in the world to fix habitat and if you don't fix that flow velocity problem in the Snake River, and there's some other problems to be worked on as well, you have a bottleneck that you are never going to solve in any other way.

Question: What were embeddedness ratings in Sulfur Creek as compared to Bear Valley?

Answer: We don't have embeddedness, per se, that I know of. We have surface fines. A kind of a weighted average from the Bear Valley systems is about in the high 40 percent range. That's a lot of sand. There are stretches of it that are a little bit cleaner and some below that mined area that are really bombed out. Sulfur Creek, depending on which set of averages you use, it's in the low 30 or high 20 percent range, which is fairly similar to what we see in other relatively pristine drainages.

Question: Didn't some of your data show a sharp decrease in survival and in emergence at about 20 percent embeddedness?

Answer: That wasn't my data, but we see similar effects of sediment on parr densities even though we are in an underseeded condition. The maximum parr densities in the lower sediment streams are higher and the break is somewhere around 20-30 percent surface fines. What you referred to, I think, is some of the laboratory models that Ted Bjornn and Burns and Stowell have worked on. But those are somewhat complementary, at least in theory.

Question: I would like to direct a question to Bill Muir. Are there other hatchery practices that you would suggest we might try to enhance smoltification and facilitate downstream migration besides increasing the photoperiod?

Answer: The first one is probably release timing. Release timing has been dictated more by getting spring chinook out of the way before they release the steelhead because of the interaction at Lower Granite Dam. The result has been that we throw them out 2-3 weeks early and they stack up above the dam and go through when they are ready anyway. So that really hasn't worked. Things like density, I think could really have an effect, if you could hold fish longer. I don't think smolt development is promoted by hatchery situations where temperatures are warm and stable from start to finish. Fish cue on temperature changes, as shown by the fall chinook data seen today, and it helps them time their smolt development a little bit better.

Question from Floor: John mentioned that when the Lower Snake Compensation Plan was developed, hatcheries were accepted by people in the basin as being the cure for the problem. Was the problem perceived as a production problem or as a survival problem? In my estimation all the production in the world by those hatcheries doesn't do a damn bit of good if the problem is survival through the system. Also, what were the alternatives offered to biologists who may have resisted hatcheries as the solution? Was there a passage solution proposed at the time these projects were being designed?

Answer: The Lower Snake River Fish and Wildlife Compensation Plan estimated that there would be 85 percent survival per dam and that the cumulative survival through the four dams would be about 47 percent. The Compensation Plan hatcheries were intended to increase the number of fish to compensate for the 53 percent loss. The Fish and Wildlife Service and the State agencies recommended that approach to the Corps and we followed those recommendations in the Compensation Plan. So we were using the options the agencies gave to us.

Question: Chip, you made the statement a while ago that you hoped that modeling would not be held hostage by the decision makers. It seems that perhaps some of the hostage-taking has already occurred. Sides have been taken in our view of the problem and in the modeling process. We're now saying that either we support this or that model or models or we are not going to support "your" models and we are going to do our own models. If we are already hostages of modeling camps, how do we get over that? How do we as scientists get our decision makers to give us the freedom to arrive at a real solution for the resource? What I have heard people say here is that scientists are taking positions that are politically correct, but are not necessarily in the best interests of the fish.

Answer: I absolutely believe that the process is being hurt by choosing camps and grabbing for the politically correct solution of the day. But I think the position-taking is independent of the models. Maybe I'm being a little defensive when I say I don't think it's the fault of the models or a fault of modeling. I think that it is the fault of the larger community--of us as professionals. But I think there is a movement afoot to try to utilize models more constructively. Jim Anderson mentioned there is enough uncertainty in the information we have to justify different points of view. The debate frequently doesn't focus on the real critical problems and may be coming at the problem from different points of view with different models, and playing out where each one leads us will be a really useful process. Some of them may look silly at the end—not all of them, because there are a lot of good ideas out there.

Comment: You brought up a point that there seems to be "no flow" and "flow" camps. I don't think those camps exist. The issue is how much water is enough to achieve our goal and what certainty bounds can you put on that estimate? How much improvement can we expect from increased flow: that's what I don't see us getting out of the modelers. I don't think that's a model problem—I think it is a modeler problem. They haven't built in the mechanisms to capture the uncertainty in the predicted values that come out of these models.

Reply: I disagree. what we can do is take some very simple relationships and show their interaction. It is nothing made up inside the model. It is an interaction of various relationships. I don't see anything wrong with doing that and I think that we have captured or at least attempted to capture the major ones, so we can give some reasonably good estimates of what we can expect from certain management actions.

Comment: One issue here is that modelers want to get everything down to simple numbers. But people like Gene are saying that behind each one of these numbers are a lot of subtle differences that can't be explained in tidy tables. Flows are easy to express in nice tidy numbers. But disease, or transport benefits involve a lot of subtleties that just aren't easily put into numbers. That is a lot of the problem here.

Comment from Moderator: About ten years ago I was in an Oregon AFS meeting and someone said we think there might an ocean carrying capacity problem because the number of hatchery fish has gone from 13 or 15 million up to 160 million and the stocks are going down in the ocean, particularly the Oregon coho production index area. And someone said, well, there are two ways to test that. We can double the number of hatchery fish produced —a very expensive test—or we can halve the number of hatchery fish produced. That's politically infeasible, because once you build a hatchery you've got to raise fish. I submit that we're stuck in the same situation here. The number of hatchery fish produced in the Snake River basin has gone up tremendously and is programmed to go up again even further. Maybe if we stay around long enough we will find out that wasn't the greatest way to go. I don't know who wants to make the decision that we are going to release less hatchery fish, but that's one possibility and we need some kinds of studies on it.

Comment: Is it a carrying capacity question? Well, I don't know. Years ago I lived in New York City and I can tell you it's stressful to live where there are a lot of people. It's stressful walking down the street. But you can get down the street at about the same speed when there are a lot of people as when there is no people. Maybe the fact that the wild fish just aren't doing so well when there's all those fish there has nothing to do with the carrying capacity issue.

I have a final observation about another potential problem area that is being neglected. We've constrained the flow issue to only the upstream river system. Look at the historic flows in the Columbia River system: much of that flow came out of the Columbia River and not out of the Snake River system. How much flow went into the Pacific Ocean? Today we have huge storage reservoirs on the Columbia, so we don't have very much flow in the lower river compared to the old days. How has this changed the Pacific Ocean and the ecosystem where the fish hit the salt water? What did it do to the predator concentrations in the marine environment? Transported fish are released by the millions below Bonneville Dam, but they aren't coming back as adults. Maybe it all has to do with what happens when the fish get to the ocean and doesn't have anything to do with the Snake River system. The problem is very complex. Many of the things people have talked about here have tried to narrow it down to a small focus and yet I suspect that it is much larger than that.

Survival of Juvenile Salmon Passing through Bonneville Dam and Tailrace

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Introduction

The efficacy of bypass systems as a safe means of passing juvenile salmon (*Oncorhynchus* spp.) around dams has generally been established by site-specific testing as each system goes into operation. Virtually all of this testing focused on the portion of the system beginning at interception of out-migrant juvenile salmonids by submersible travelling screens, and ending just prior to release into a conduit or channel through which fish were carried to the tailrace below the dam. There have been few rigorous assessments of fish survival through an entire bypass system, from forebay to tailrace or beyond, at any of the dams.

The principal constraint in conducting such tests is the difficulty of obtaining a statistically unbiased sample of fish exiting a bypass system prior to reaching the next dam downstream. Assessment downstream is often complicated by the uncertainties of collection efficiency. This is not the case at Bonneville Dam, the lowermost hydroelectric project on the Columbia River, where approximately 157 km of free-flowing river separate the dam from the estuary. An established sampling station is located at the head of the estuary at Jones Beach (River Kilometer 75; Figure 1). More than 20 years of sampling, using beach and purse seines to collect out-migrating juvenile salmon, has demonstrated that an unbiased estimate can be made at this site (Dawley et al. 1986).

There are several compelling reasons for focusing research on fish passage at Bonneville Dam. As the last dam on the Columbia River, Bonneville Dam is in the critical position of passing more juvenile salmon than any other dam in the system. Moreover, no thorough assessment of passage survival has been conducted at the dam since completion of the spillway flow deflectors in 1975, the Second Powerhouse in 1983, and the two downstream migrant bypass systems in 1981 and 1984. Information specific to each of these separate passage routes is needed for management of fish passage relative to power production.

Passage Route Survival Comparisons

In 1987, the National Marine Fisheries Service (NMFS), in cooperation with the U.S. Army Corps of Engineers (COE), began a multiyear study to evaluate survival of subyearling fall chinook salmon *O. tshawytscha* passing Bonneville Dam. During June, July, and August, 1987 through 1990, groups of differentially marked chinook salmon were simultaneously released to pass Bonneville Dam via the spillway, the Second Powerhouse turbines, or the Second Powerhouse bypass system (Figure 2). Additional releases were made in the tailrace at the downstream edge of the turbine boil, about 2 km downstream from the dam. To date, about 8 million fish have been released. Estimates of short-term relative survival were based on recoveries of juveniles by beach and purse seines at Jones Beach. Estimates of long-term relative survival were based on recoveries of tagged adult fish from the fisheries and from hatchery escapement.

The most striking finding of this study was that differences in estuarine recoveries of juvenile salmon from turbine and bypass release groups suggested little survival benefit associated with the bypass system. In 1987 and 1988, recoveries of bypass-released groups were significantly less than recoveries of turbine-released groups; mean differences were 13.3 and 16.6%, respectively. In 1989 and 1990, recoveries of bypass-released groups were also less than recoveries of turbine-released groups, though not significantly; mean differences were 3.1 and 2.6%, respectively. The difference between data sets may be associated with greater river flow, resulting in higher tailwater elevation during tests conducted in the last 2 years (Figure 3).

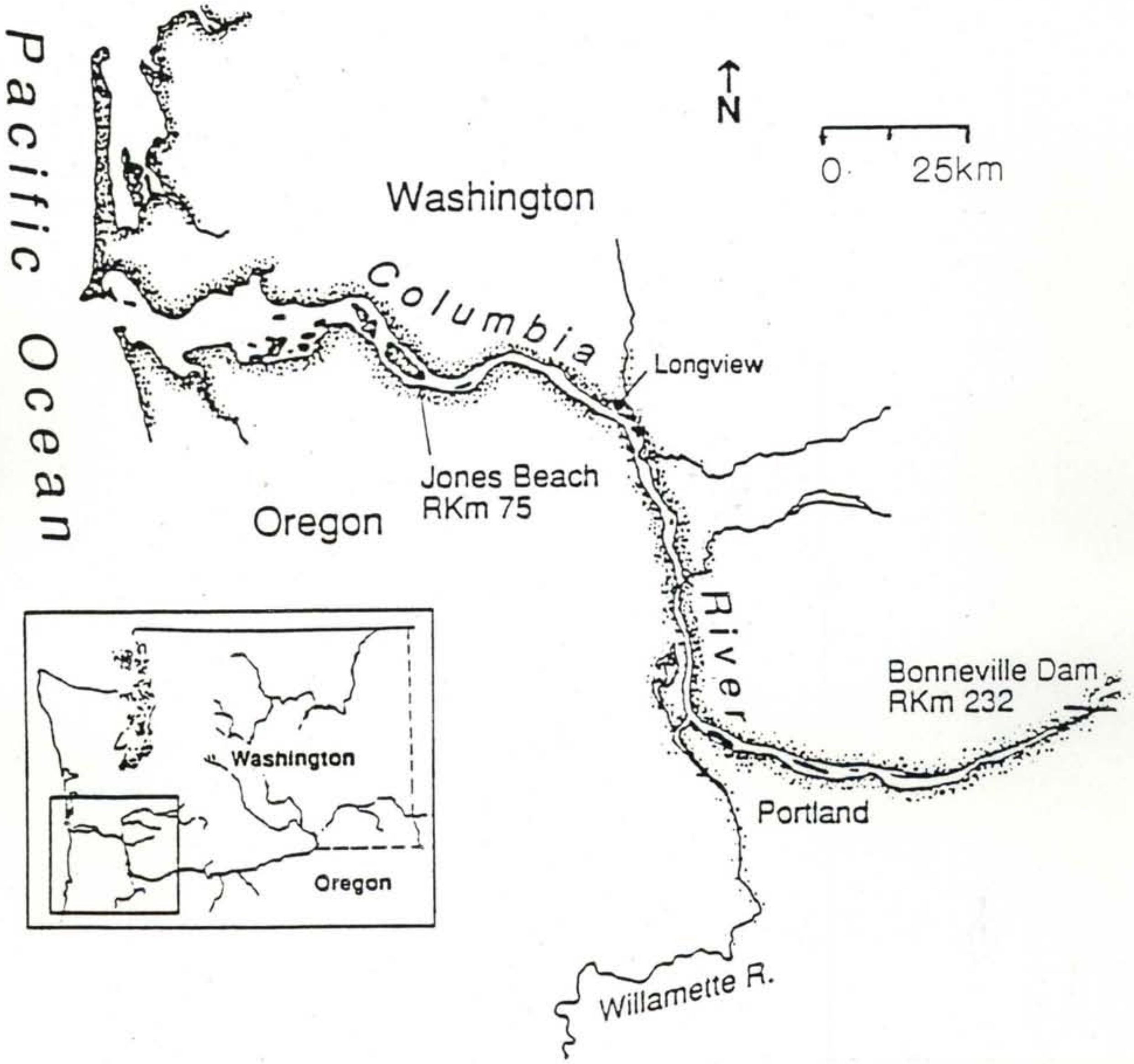

Figure 1. The lower Columbia River showing locations of Bonneville Dam and the estuarine sampling site at Jones Beach, Oregon.

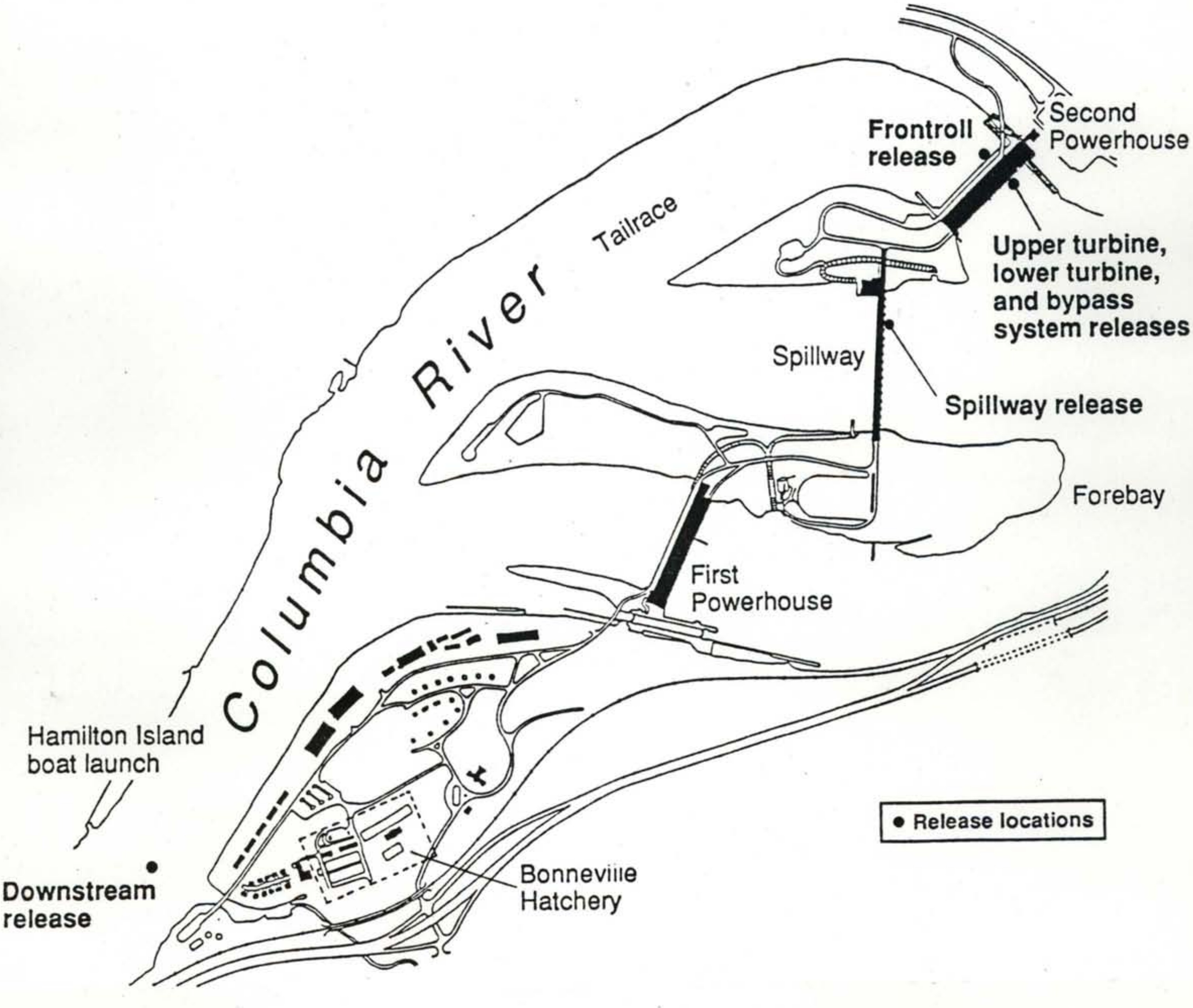

Figure 2. Schematic of Bonneville Dam and vicinity showing release locations for subyearling chinook salmon during 1987-90 studies.

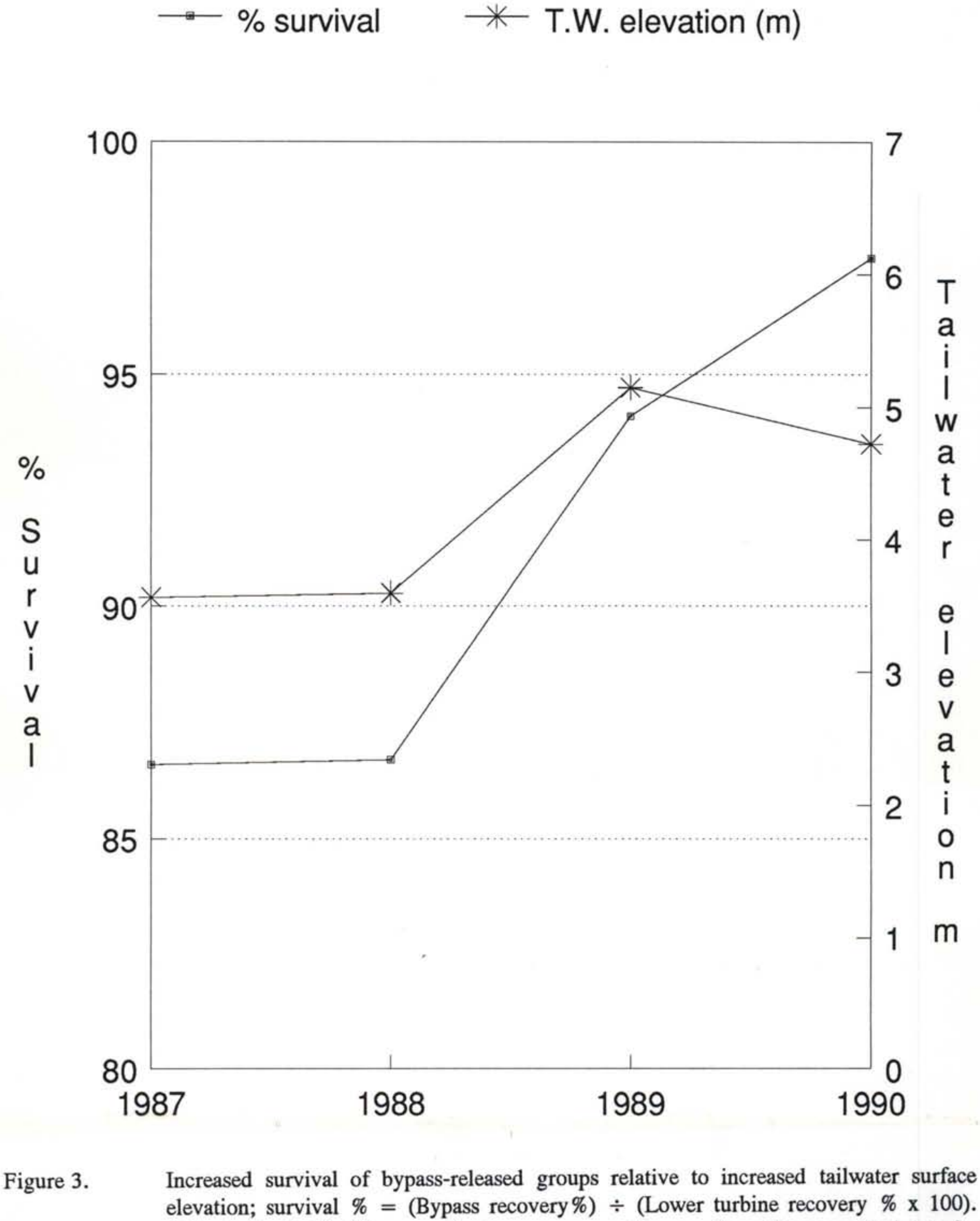

Figure 3. Increased survival of bypass-released groups relative to increased tailwater surface elevation; survival % = (Bypass recovery%) ÷ (Lower turbine recovery % x 100). Only the last half of the annual releases were used to provide uniform survival data for comparing low tailwater test conditions.

Higher tailwater elevation has diminished turbulence and reduced water velocity from 8.1 to 7.6 m/sec within the 1-m diameter bypass conduit. In addition, it has diminished shear forces at the conduit terminus.

Comparisons of recovery differences between bypass-released and other release groups were also made, but include fewer years of comparison (Table 1). On the basis of 3 years of releases, recoveries of bypass-released groups averaged 8.3% less than recoveries of tailrace-released groups. From 2 years of releases, recoveries of bypass-released groups averaged 17.4% less than recoveries of downstream-released groups. On the basis of data from a single year (1989), bypass-released groups averaged 16.6% less than spillway-released groups. This latter comparison is noteworthy since spillway passage has long been believed to be the safest route of dam passage and was considered similar to bypass passage.

Although several years remain before data on adult returns are complete, preliminary results suggest that returns of bypass-released fish are not significantly different from those of turbine-released fish. Again, this suggests a lack of benefit from bypass passage (Ledgerwood et al. 1990, 1991).

Evaluation of the Bypass System

Results of passage survival tests prompted us to focus research efforts on detrimental impacts to out-migrating juvenile salmon using the bypass system. Decreased survival may be a consequence of physical damage, occurring during passage through the system; increased predation after egress from the bypass discharge conduit; or a combination of both.

The design and location of the bypass conduit terminus were engineered to provide out-migrants the best possible protection against predation by birds and fish. The supporting structure for the 1-m diameter conduit is a teardrop-shaped column projecting 9 m upward from the river bottom, the top of which is 7-14 m below the water surface. The terminus is located in relatively high-velocity water about 76 m downstream from the dam, 85 m from the north shore, and 30 m downstream from the turbine discharge boil. The river bottom is smooth and the distance from any geologic relief was thought to eliminate predator sanctuary near out-migrating juvenile salmon.

Initial Investigations

Initial investigations of the physical features of the bypass system by NMFS and COE provided little evidence of problems. A video inspection of the discharge conduit revealed no structural problems sufficient to cause injuries to fish. At operating conditions identical to those of survival tests, water velocities adjacent to the discharge monolith varied from 1 to 1.6 m/sec, similar to model-predicted velocities. Northern squawfish *Ptychocheilus oregonensis* are thought to be the primary piscivore on juvenile salmon in the Columbia River (Poe et al. 1991; Vigg et al. 1991). Literature regarding habitat suitability for northern squawfish suggested that velocities of that magnitude would be exclusionary (Faler et al. 1988). Purse seining at the bypass outlet produced little evidence of injury or mortality, but insufficient fish were recovered to allow rigorous assessment.

Trap-Net Method

In 1990, researchers began using a trap-net recovery system to assess the physical condition of out-migrants following passage through the bypass system (Figure 4). The trap net was attached directly to a steel carriage permanently affixed to the outlet monolith. The objective was to identify which segment of the system was detrimental to juvenile salmonids and to assess any differences at various tailwater elevations. Marked hatchery and run-of-the-river fish were released at various locations in the bypass system and trap net. Fish were then recovered and evaluated for stress, scale loss, injury, mortality, and 48-h delayed mortality. To assess whether the trap net captured live and moribund fish in the same percentages, recently killed fish were released through the bypass system in conjunction with live fish.

TABLE 1.—Differences in relative survival between fish passing through the bypass system and other passage routes at Bonneville Dam based upon juvenile recovery data from estuarine sampling.

Release site/ passage route	Percent difference of bypass recoveries from indicated treatment[a]				
	1987	1988	1989	1990	Average
Turbine: Released at the ceiling and mid-depth of the turbine intake. Passage through the turbine and through the PH-2[b] tailrace.	-10.8*	-13.6*	-3.3	-2.5[c]	-7.6*
Tailrace: Released at the downstream side of turbine discharge boil. Passage through the PH-2 tailrace.	----	-14.1*	-7.3	-3.6	-8.3*
Spillway: Released 0.5 m above spillway crest. Passage over the spillway, through stilling basin and spillway tailrace.	----	----	-16.6*	----	-16.6*
Downstream: Released downstream from dam and tailraces, at a swift-water site.	----	-23.1*	-11.6*	----	-17.4*

[a] Calculated using annual means for recovery percent of treatment groups, where: BY = bypass, and TR = other treatment groups/passage routes [(BY% - TR%) ÷ TR%] x 100.

[b] Abbreviation for Second Powerhouse.

[c] Only the mid-depth release site was used, to provide increased numbers of replicates.

* Significant at $P = 0.05$.

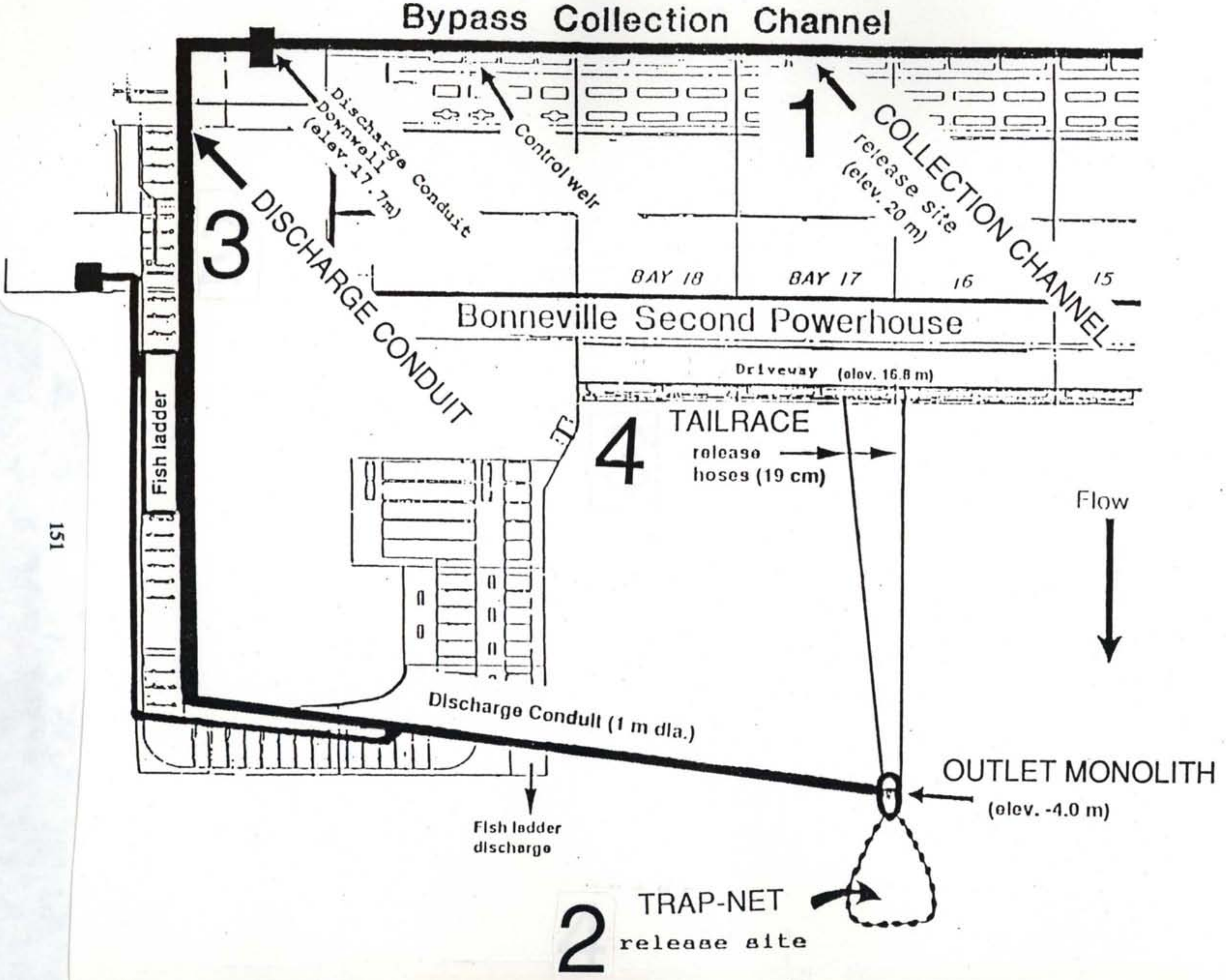

Figure 4. Schematic of the downstream migrant bypass system at Bonneville Dam Second Powerhouse; fish release sites are numbered.

Trapping Results

The trap net recovered 80-100% of live test fish and 93-100% of killed fish released into the bypass channel. The high recovery rate of killed fish allowed us to assume that injured, moribund, and dead test fish exiting the bypass were proportionally represented in recovery data.

Tests conducted during the juvenile migration period at moderate tailwater elevations (4.9-6.1 m) showed some impacts from bypass passage, primarily increased stress and scale loss, with slight increases of injury and mortality. However, some groups showed substantial impacts from bypass passage. Run-of-the-river yearling and subyearling chinook salmon and coho salmon *O. kisutch* incurred high percentages of scale loss (9-29%; Figure 5) and individual fish suffered severe scale loss. In tests with subyearling chinook salmon, hatchery fish incurred 0.3% injury, 5.6% direct mortality, and 2.1% delayed mortality; and run-of-the-river fish incurred 3.8% injury, 2.4% direct mortality, and 7.6% delayed mortality.

Assessment of blood plasma cortisol, glucose, and lactate--used to evaluate stress--indicated significantly greater stress to bypass-released fish than to controls. Concentrations of plasma cortisol were high for an 18-h period following passage (Figure 6). Test fish stressed in the laboratory by dip netting to establish comparison points of known stress showed cortisol levels of similar magnitude to those produced from bypass passage.

Additional tests conducted at low tailwater elevations (2.7-3.2 m) may indicate high variability in passage conditions, causing intermittent high mortality. The high velocity and turbulence within the system during tests was similar to conditions that migrants would encounter during years of low river flow. Mortality ranged from 6 to 51% for subyearling chinook salmon and from 0 to 32% for subyearling coho salmon (Figure 5). Impacts to fish released at the midpoint of the bypass system were less, 2-40% mortality for subyearling chinook salmon and 0-19% mortality for subyearling coho salmon.

Two potential sources of hazard within the bypass discharge conduit were identified by NMFS biologists and engineers: entrained air may be causing severe pressure fluctuations throughout the conduit, and a short-radius elbow at the upstream end of the conduit may be producing negative pressures. Biological evaluation is in progress.

Aspects of Bypass Systems That May Cause Decreased Survival

Coincidental studies of northern squawfish in the tailrace of Bonneville Dam indicated greater predation on fish leaving the bypass system than at other locations at the dam. Ward et al. (1992) stated that trolling with lures at the bypass outlet produced substantially higher catches of northern squawfish than at any other location in the forebay or tailrace of the dam. In 1990, passage survival tests indicated that northern squawfish consumed greater percentages of bypass-released fish than tailrace- or turbine-released fish (Thomas Poe, unpublished report, U.S. Fish and Wildlife Service, Columbia River Field Station).

Reduced survival of test fish released through the Bonneville Dam Second Powerhouse bypass system in 1987-90 probably resulted from both physical impacts of passage through the bypass discharge conduit and predation during migration through the tailrace. Physical problems within the bypass conduit will be remedied insofar as possible, but since the conduit is 287 m long, mostly 1 meter in diameter, and partially submerged, it may be difficult to identify and correct all problem areas. However, the inherent impact from predation following egress from the system cannot easily be remedied.

Predation may be an insurmountable problem as a result of (1) increased stress from passage causing diminished avoidance reactions [laboratory studies showed that severe stress or severe turbulence caused loss of equilibrium and abnormal avoidance behavior (Groves 1972; Sigismondi and Weber 1988)]; (2) point-

IMPACTS FROM BYPASS PASSAGE

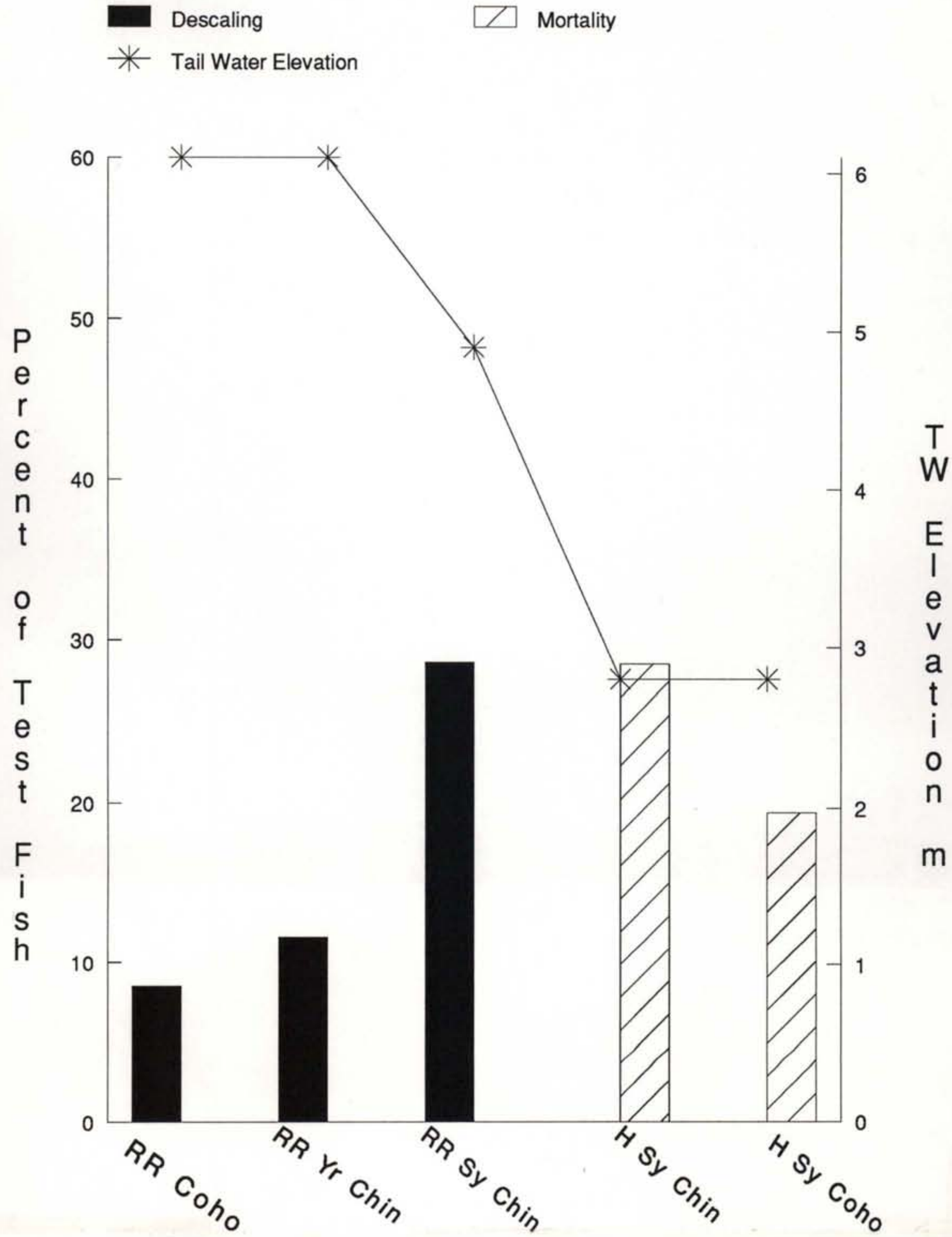

Figure 5. Average descaling and mortality percentages of test fish in relation to tailwater (TW) elevation during tests (RR = run-of-the-river, H = hatchery, Yr = yearling, Sy = subyearling, and Chin = chinook salmon).

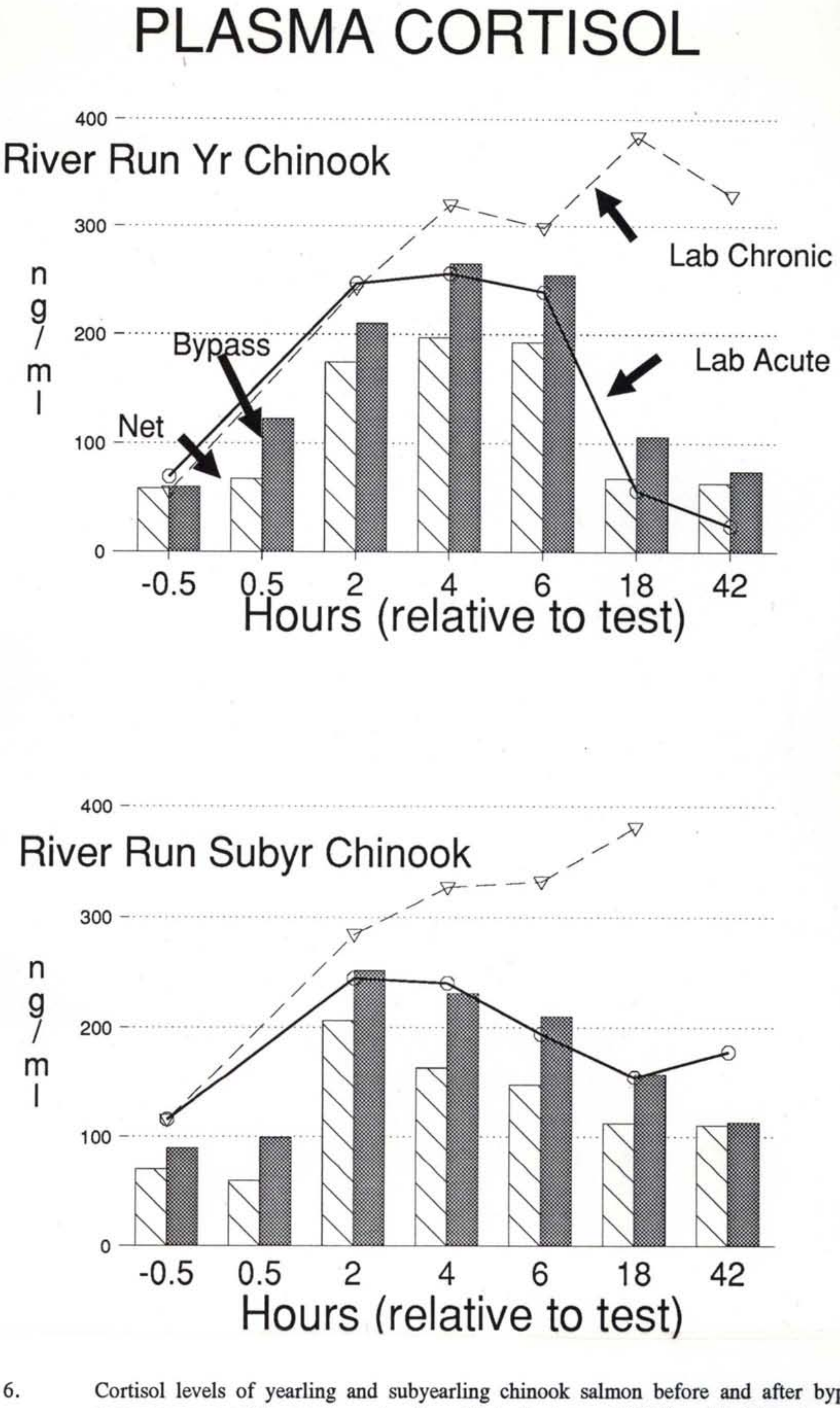

Figure 6. Cortisol levels of yearling and subyearling chinook salmon before and after bypass passage compared to counterparts released into the trap-net (Net) and to laboratory test fish stressed by dipnetting (Acute) and by continuous crowding (Chronic).

source release from the bypass allowing predators to congregate; 3) migration through a low-velocity tailrace basin providing a large area of suitable habitat for northern squawfish; and (4) a bypass outlet location on the north side of a tailrace that angles to the south about 90°, tending to direct out-migrants shoreward toward rip-rap areas--prime habitat for northern squawfish.

In the passage survival tests of 1987-90, estimated survival for test fish released 2.5 km downstream from the dam was significantly higher than for fish released into the bypass system. The physical conditions at the downstream release location that most probably allowed higher survival were (1) high water velocity--1.5 to 2.1 m/sec; (2) long distance from shore--about 100 m; (3) rapid downstream dispersal of fish, resulting in decreased juvenile salmon density in the migration route and increased time for orientation prior to encountering predators; (4) release where current direction was parallel to the shoreline; (5) lack of predator attraction from a continuous egress of juvenile salmon at a single location or along a localized migration route; and (6) nighttime releases that minimized avian predation.

Summary and Conclusions

1. Trends observed in the juvenile recovery data suggest that bypass passage has not substantially improved survival as compared to turbine passage for summer-migrating juvenile chinook salmon at Bonneville Dam; however, the final conclusions regarding differences in passage survival must await analyses of all adult returns.

2. Bypass passage appears to cause significant stress, loss of scales, and some direct mortality. During summertime low river flows, the resulting low tailwater elevations appear to aggravate mortality during passage.

3. Survival of fish leaving the bypass system appears to be diminished by northern squawfish predation.

4. Conditions that appear to increase survival of downstream- released fish over bypass-released fish include high water velocity, long distance to predator habitat, current direction parallel to the shoreline, low level of stress for migrants at river entry, lack of predator attraction from continuous availability of juvenile salmonids, and nighttime release of fish to limit avian predation.

5. Conditions thought to decrease survival of out-migrating juvenile salmonids at the Bonneville Dam Second Powerhouse bypass system may be important at other dams, and should be investigated.

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Use of Biological Criteria for Siting of Bypass Outfalls

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Introduction

Juvenile bypass systems have been installed at most of the Lower Columbia and Snake River Projects. As the construction of the juvenile bypass systems has progressed, new information has become available and has been incorporated into the design of the new bypass systems. This has been the case with the design of The Dalles juvenile bypass release site.

Several types of bypass release points or juvenile outfalls have been constructed in the Lower Columbia and Snake River Projects. These include full flow systems (John Day Dam) and partial flow systems (all other projects). The outfalls also vary with underwater release points (Bonneville I and II) and above water releases (most other projects). One parameter common to all the projects is that each system has one release point, generally located in the immediate tailrace area.

Location of the juvenile release site is a critical factor in achieving positive survival benefits from the juvenile bypass system. Preliminary information from the Bonneville survival studies indicate that juvenile subyearlings passing through the bypass system survived 8% less than those going through the turbines and that subyearling juveniles placed 1.5 miles downstream survived 10% better than the turbine released juveniles (Ledgerwood, et al. 1990). Poe and Rieman (1988) estimated that 22% of the juvenile losses in the John Day pool occurred in the McNary tailrace area. It is reasonable to assume that a large percentage of the predation is occurring in the tailrace zones below the outfall due to the concentration of juveniles from the point source release. In addition, Poe (pers. comm, 1991) found the highest concentration of predators and the highest consumption rates at The Dalles Project immediately below the ice trash sluiceway. Many field personnel have also observed large concentrations of predators near the juvenile release site of the Bonneville first powerhouse especially following release of truck transported juveniles. Information from these studies and observations suggests that in order to acheive the intended benefits of the juvenile bypass system, site selection of the juvenile release site is very important. Based on information from the Bonneville second powerhouse survival study (Ledgerwood, et al. 1990) high mortality rates associated with the release site and inside the bypass facility may have cancelled out the positive survival benefits of the entire juvenile bypass system.

Methods

New physical criteria were developed, based on the best available information of juvenile salmonid and predator behavior, to assist in the design of the juvenile release site for The Dalles Bypass System. The criteria were developed in conjunction with the fishery agencies and Tribes. These criteria include:

1. water velocity at juvenile release site
2. recovery area downstream of the release site
3. distance from in-water structures or backwater areas
4. dispersal of flows downstream of the release site

It is not expected that meeting these criteria will eliminate predation on juvenile salmonids at the selected release site, but should provide an area that minimizes predation. It is likely that predators will move to areas where concentrations of prey are readily available. The assumption is that the release site be located where predator capabilities on selecting prey are diminished.

Water velocity at previously constructed juvenile release sites has been between 3.0 - 3.5 fps. Recent information from a squawfish performance evaluation suggest that velocities at approximately 3.2 fps may allow squawfish to hold for 120 minutes (Poe, pers. comm, 1991). However, this study also suggests that squawfish holding ability diminishes rapidly at velocities above 3.2 fps. Based on this information, velocity criteria for juvenile release sites should be 3.5 fps or greater.

The other criteria described above (2-4) are subjective but important in selection of a release site. These criteria were used in defining the best available release site in the tailrace of The Dalles Project. While these criteria are debatable, they are difficult to improve upon without additional information on predator and juvenile salmonid behavior.

A method was needed to estimate differences in relative survival between two alternative release sites. Information from previous studies suggest that timing and flow may be major factors that affect predation rates on juvenile mortality immediately below the projects. In order to assess flow properties, it was necessary to describe the physical characteristics near and downstream of the release sites.

A physical model (1:80 scale) was constructed at the U.S. Army Corps of Engineers Waterways Experiment Station (WES) in Vicksburg, Mississippi, to gather hydraulic information necessary to select an outfall site for The Dalles juvenile bypass system. The model limits are approximately 1.5 miles upstream and 1 mile downstream from the spillway. The general model was used to observe and document flow patterns and to gather velocity information for the expected flow range and water passage modes that will occur in the tailrace environment.

Several types of information were collected with the model. Velocities in the forebay and tailrace zones were evaluated with video camera technology. Float tubes, representing the top 25 feet of the water column, were placed at various locations in the model. Float tubes were tracked with video cameras and velocities were derived by computer analysis for each test pattern. Float tubes representing the top two feet of the water column were utilized in shallow tailrace areas.

Dye and confetti traces were also video tracked through the tailrace. Dye represents the full depth spectrum and confetti indicates surface areas only. This method provides information for dispersal of flows from a given release point.

Test flows were established to evaluate the flow distribution normal to The Dalles Project during the fish passage season. Flow levels evaluated ranged from 50 kcfs to 400 kcfs. The distribution of the flow patterns tested were:

Test	Total Flow	Powerhouse	Spill	Pattern
1	50,000	50,000	0	
2	100,000	100,000	0	
3	150,000	150,000	0	
4	200,000	200,000	0	
5	250,000	250,000	0	
6	300,000	300,000	0	
7	350,000	350,000	0	
8	300,000	250,000	50,000	adult
9	400,000	250,000	150,000	adult
10	130,000	100,000	30,000	juvenile
11	310,000	250,000	60,000	juvenile

Adult and juvenile spill patterns are from the Fish Passage Plan for 1992 (USACE, 1992).

Results

Two juvenile release sites were identified with the observational and velocity information (Figure 1). These two sites met the velocity criteria under a majority of flow levels and under various distributions of flow through The Dalles Project. However, neither site nor other potential release sites in the Dalles tailrace could meet the velocity criteria with flows of 150,000 cfs or less.

Flow levels from 150,000 to 350,000 cfs (powerhouse flow) easily met the velocity criteria at either release site and extended downriver. Water speed at the upstream site slowed in front of the spillway stilling basin (often less than 3.5 fps) and had flow vectors that moved over a shallow shelf area located downstream of the main channel. In addition, several backwater areas, located downstream of the upstream release site, were observed in close proximity to the main flow paths from the powerhouse channel. It is likely that predators will inhabit the backwater and shallow shelf areas. Flow vectors, near the downstream release site, were oriented down the main channel and maintained good water speed until out of model range. The downstream release site also has a large backwater area created by the navigation lock approach channel where predators will likely be present. However, by extending the release site out in the channel, the flow paths from the release site stay primarily in mid-channel. Assuming that juvenile salmonids follow the main flow paths and do not seek backwater areas, predation rates should be lower at the downstream release site in comparison to the upstream site.

Flow conditions that include spill, in either the adult or juvenile spill pattern tests, create unfavorable flow conditions for the upstream site. Flows from the spillway intercept the powerhouse channel flow resulting in flow vectors oriented toward the downstream shelf. This reduces the speed of water coming from the powerhouse channel, especially in the upper portion of the water column (top 25 feet) where a majority of the juveniles are expected to occur.

Velocities appear to be adequate in a majority of the flow ranges at both release sites, but areas downstream of the release sites favor selection of the downstream location. In lower flow ranges, neither release site can meet the established velocity criteria. Other alternative release strategies need to be developed to meet criteria, if determined to be appropriate, in the lower flows. Short haul transport of fish from the Dalles to downriver locations has been considered as a potential alternative during low flow conditions. Conceptually, this program would hold juveniles during periods of low river flows and release them downstream (1-4 miles) on a daily basis. The short haul concept is derived from information from release of Bonneville hatchery fish from Tanner Creek versus a mid-river release (Ledgerwood, unpublished data, 1990). This study concluded that based on recovery of juveniles at Jones Beach, there was 33% increased survival rate for fall chinook transported and released in mid-river compared to Tanner Creek released fish.

Summary

The primary objective in locating the juvenile release site is to minimize predation of juveniles exiting the bypass facilities. Even if predator control methods are effective, it is likely that substantial predation will occur on juvenile salmonids in the tailrace environment. To meet this objective, physical criteria were developed to assist in design and location of the juvenile bypass release site. The release site is an important element in the bypass facility and based on previous designs and results, three factors should be incorporated into design of a release site:

1. Meet the established criteria based on the best available information.

2. Flexibility for change should be incorporated into the design as new information and technology develops.

3. The complete bypass facilities should be evaluated to insure survival benefits are being realized.

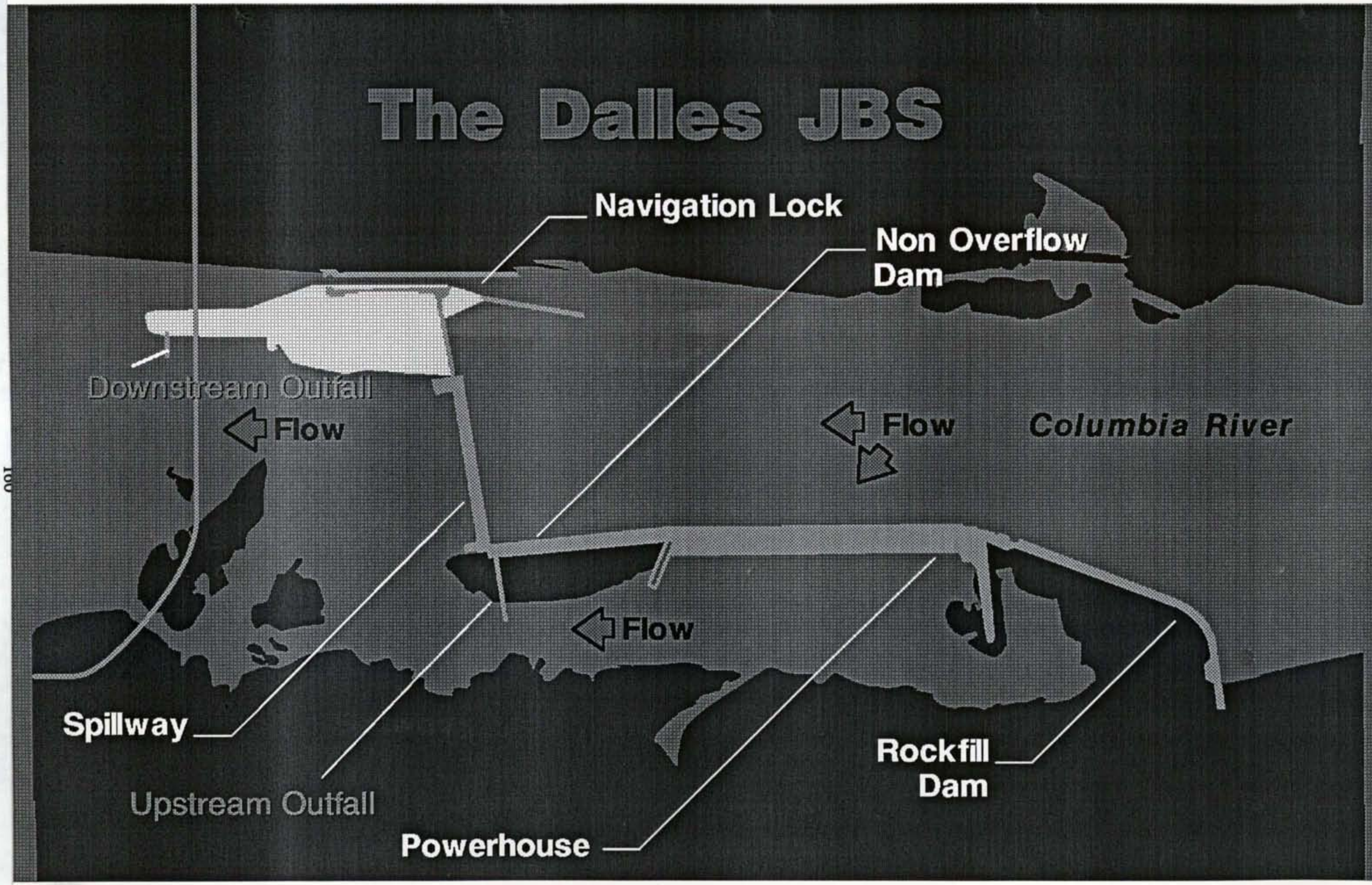

Figure 1. The Dalles Dam and alternative Juvenile release sites.

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Smolt Monitoring Technologies

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Introduction

Smolt monitoring will continue to be an important management tool for evaluating juvenile fish passage at hydroelectric facilities. Some of the current standard methods, such as the use of dipping baskets and fyke nets for determining fish guidance efficiency (FGE), are not only labor intensive, but frequently result in the sacrifice of many of the fish sampled. These practices are becoming increasingly difficult to justify, particularly in light of the recent listing of the Snake River sockeye as endangered, and the Snake River spring/summer and fall chinook runs as threatened. The Corps Fisheries Field Unit has begun investigation of nonlethal technologies to obtain vital smolt passage information.

Methods

The investigation into nonlethal technologies for smolt monitoring involved an extensive literature search, using specific key words to search literature databases. The resulting list of article abstracts were read and if the technology sounded promising, the article was ordered and read. Authors or scientists were contacted on occasion to discuss these technologies specifically for smolt monitoring applications. Advantages and disadvantages of each technology were then listed and only the most promising ones were proposed for evaluation.

Results and Discussion

Many possible techniques for monitoring smolt passage were researched. Most, however, were limited to short-range detection and required well-controlled conditions or the trapping and handling of fish. Three technologies were identified as having the most potential for use in smolt monitoring as well as being nonlethal. They are (1) advanced underwater imaging techniques, capable of providing images with adequate resolution, range, and field of view; (2) LADAR, laser light capable of rapidly scanning or screening a cross-section of water, with the potential of species recognition in the future; and (3) advanced hydroacoustic techniques, capable of detecting fish passing a known sampled volume of water.

Hydroacoustic technology has been used extensively in the past decade for the following purposes: (1) spill monitoring programs (Johnson et al. 1985 and 1987; Kuehl, 1987; Ouellette, 1988; Steig et al. 1985); (2) determining vertical and horizontal powerhouse passage distribution (Johnson et al. 1985 and 1987; Kuehl, 1987; Ouellette, 1988; Magne et al., 1983 and 1986; McFadden et al. 1990a and 1990b; Nagy et al., 1985; Steig et al. 1985); (3) monitoring ice and trash sluiceway passage (Johnson et al., 1987; Stansell et al., 1990; Steig et al. 1985); (4) determining fish turbine passage (Stansell et al. 1991); and (5) determining FGE (Magne et al. 1986 and 1989; McFadden et al. 1990b; Nagy et al. 1985; Thorne et al. 1989).

The kinds of information that can be obtained from hydroacoustics are (1) vertical, horizontal, temporal, and seasonal passage distributions; (2) relative daily passage rates and abundance estimates, and year-to-year fluctuations; (3) real-time estimates of passage; and (4) FGE estimates (to some degree). Types of information that cannot be obtained or that may be of questionable value are (1) species composition; (2) condition of fish or their lengths and weights; (3) actual numbers of fish passing; or (4) actual effectiveness of spill or sluiceways. Hydroacoustics may give very rough indications of effectiveness, but it is very limited.

Hydroacoustic technology has shown us the following: (1) most juvenile fish pass the powerhouse and spillways during the hours of 2000 to 2400; (2) most fish pass the sluiceways during the afternoon hours;

(3) fish are about 10' deeper at night than during the day, hence nighttime spill is more effective and daytime FGE may be higher; (4) fish approach the dams at greater depth in the summer (subyearlings) than in the spring (yearlings) by 10' to 15'; and (5) most fish pass through the units or spill bays that are near the shorelines or that have the most flow. Indications have been that the sluiceways are effective means to pass fish, particularly during daylight hours.

The following are advantages of hydroacoustic techniques: (1) they are nonlethal; (2) long-term sampling is possible; (3) sampling of multiple sites simultaneously is possible; (4) they are not labor intensive; (5) real-time estimates can be made for real-time management decisions. Disadvantages of hydroacoustic techniques are: (1) they are unable to determine species, lengths, or condition of the fish; (2) target identification may be difficult depending upon conditions; (3) intitial setup cost is high; (4) comparison of estimates of fish passing the powerhouse vs. spillway are not advised because of different deployments, different fish aspects, and other factors; (5) it is difficult to put confidence limits on estimates (but a range of estimates is possible); and (6) typically, passage at shallow passage facilities such as sluiceways is underestimated.

The Corps is currently investigating methods to reduce extraneous noise interference with hydroacoustic target identification and split-beam technology. This should allow estimates to be made from a known sampling volume, improving the accuracy of the estimates.

Advanced underwater imaging technologies were investigated for possible application to smolt monitoring (Nagy, in preparation). The simplest technique is to use conventional underwater video cameras and to reduce backscatter problems by separating the light source from the camera. This technique has been proven and is inexpensive, but the disadvantages are that the range of detection is still short, the presence of lights themselves may influence smolt behavior, and the potential for improvement is expected to be much less than for laser scanning methods.

Polarization techniques are also designed to reduce backscatter and reduce reflection from non-fish targets, but the amount of light reaching the camera is reduced and light sources may affect the behavior of smolts. This technique, in combination with separation of light and camera, may nonetheless be acceptable for certain applications.

Range-gated video is another technique which improves image contrast by decreasing the backscatter that competes with the reflection from the target. This, in turn, results in a better signal-to-noise ratio. Range-gated video usually involves an extremely short-duration, powerful pulse of light or laser sent out towards the target, and the camera is gated open to receive the signal after a designated time. This increases the range of viewing over conventional video methods. Unfortunately, this technique is range-dependent, requiring a known, limited range of camera-to-target distance. An alternative would be to use an array to gate a multitude of ranges, but this would be very expensive.

Synchronous scan video is another technique which improves image contrast, much as range-gated video does. A narrow beam of light or laser scans the target while the light detector is synchronously scanned to receive the light. The transmitted beam and the receive cone intersect only at the target. But like range-gated video, the effective depth of field is small and the range to the target needs to be known.

Acoustic imaging has the benefit of not requiring light, which may affect smolt behavior, and is not affected by turbidity. Unfortunately, little or no work has been done in this field in the past decade, although there may be some potential for high resolution scanning sonars with 3D capability that are currently being developed for marine use. A disadvantage of older acoustic imaging systems is its poor resolution, making smolt identification nearly impossible.

LADAR is a promising technology for smolt monitoring work. The basic concept is similar to radar and active sonar. A narrow beam of pulsed laser is transmitted into the water, and objects in the beam reflect the light back to the source, where it is detected. High rates of scanning are possible. The laser is pulsed and a scanner directs the light pulses to cover the field of view. Reflected light is then received by optical receivers and converted to an analog signal that is sent to a signal processor for detection processing. A similar method is to use a laser light screen. An array of such lasers covering a cross-section of water may be able to detect passing fish as well as distinguish fish from other "non-targets." The advantages of lasers are that these narrow, high-powered beams of light can be transmitted through turbid water further than conventional light sources. Species differentiation by means of spectral analysis may also be possible. The major disadvantage of this technology is that it is still in the developmental stage and it is expensive.

Summary

1. Smolt monitoring techniques in the future need to be nonlethal and nonobtrusive to fish.

2. Three technologies were identified as potentially useful in smolt monitoring. They are (1) advanced underwater imaging techniques, capable of providing images with adequate resolution, range, and field of view; (2) LADAR, laser light capable of rapidly scanning or screening a cross-section of water and potentially having species recognition; and (3) advanced hydroacoustic techniques, capable of detecting fish passing a known sampled volume of water.

3. Advanced underwater imaging techniques are capable of decreasing backscatter problems and improving the range over conventional underwater video techniques, but most require an external light source which may affect fish behavior, or require a known camera-to-target range with a small field of view, or have poor resolution.

4. LADAR technology has much potential, in not only extending the range of detectability in turbid water over other imaging techniques, but also in species identification by the use of spectral reflectivity of the various species. The biggest drawback is the large initial expense during the developmental period.

5. Advanced hydroacoustic techniques have the following advantages: They require no lights, the techniques have already been developed and used for many applications, and reliability and accuracy can be improved by more accurately defining the sampling volume and eliminating sources of noise for better target identification.

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The Effectiveness of Extended Submersible Traveling Screens and Bar Screens for Guiding Juvenile Salmonids at McNary Dam, 1991

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Introduction

Research on devices to guide downstream migrating juvenile salmonids out of turbine intakes at dams on the Columbia and Snake rivers has been in progress for about 25 years. Early research led to the development of submersible traveling screens (STS), first installed at Ice Harbor Dam in 1969 and at McNary Dam in 1981. Most Columbia and Snake River hydropower projects now have STS to divert juvenile salmonids away from turbines into a bypass system to either collect and transport them to release sites below Bonneville Dam or to bypass them to the river below the dam.

Guidance of juvenile salmonids varies considerably depending on (1) fish species and run, (2) time of year, (3) environmental conditions such as river flow and water temperature, and (4) physical features of a particular project. Fish guidance efficiency (FGE) has varied widely, ranging from as low as 4-5% for subyearling chinook salmon *Oncorhynchus tshawytscha* at Bonneville Dam to over 80% for steelhead *O. mykiss* at several dams. Subyearling chinook salmon have historically guided poorly, due to their tendency to migrate deeper in the water column, with FGE averaging about 35% basinwide. Research at McNary Dam indicated that FGE for yearling chinook salmon, coho salmon *O. kisutch*, and steelhead was greater than 70% (Swan and Norman 1987); however, in previous tests, guidance for subyearling chinook salmon ranged from 33 to 60%, although it was generally less than 50% (Brege et al. 1988).

In an effort to improve FGE for outmigrating juvenile salmonids, the U.S. Army Corps of Engineers (COE) designed extended submersible traveling screens (ESTS) and extended submersible bar screens (ESBS) to test at McNary Dam in 1991. The extended screens were 12.2 m (40 ft) long, compared to 6.1 m (20 ft) for standard screens. If extended screens improved FGE significantly for the target species, the COE would consider installing extended screens at appropriate hydropower projects on the Columbia and Snake Rivers. Yearling chinook salmon were the target species during the spring out-migration, while subyearling chinook salmon were targeted during the summer out-migration. Data for other salmonid species were collected as available.

The objectives for the 1991 studies at McNary Dam were to

1. Determine the depth distribution of juvenile salmonids passing through the turbine intakes during the spring and summer out-migrations.
2. Evaluate the ability of extended submersible traveling screens and extended submersible bar screens to guide fish during the spring and summer out-migrations.
3. Determine the effects of extended guidance devices on juvenile salmonid descaling.

Methods

Vertical Distribution Measurements

Vertical distribution measurements were conducted without the extended screens in place using standard materials and methods (Krcma et al. 1986). With standard length screens, the fyke-net frame is an integral part of the screen framework. Since the framework of the extended screens, but not the screens themselves, filled the entire gatewell slot from the turbine floor to the ceiling, fyke nets were attached to a separate fyke-net frame placed in the downstream gateslot (Figure 1). The entire frame was fitted with fyke nets, but only nets in the center of the three columns had cod-ends. The fully netted fyke-net frame produced more uniform flow patterns within the test slot. The fish that entered the gatewell volitionally were captured using a dip basket (Swan et al. 1979). All fyke-net catches were expanded by three to estimate the total numbers of fish passing through each net level. Dividing the gatewell catch plus the number of fish caught in the top three half-nets by the total number of fish entering the turbine intake (gatewell catch plus total fyke-net catch) provided the estimate of theoretical fish guidance efficiency (TFGE). Each of the two vertical distribution measurement series for yearling chinook salmon consisted of four replicates, one each day. Only one vertical distribution measurement series, consisting of three replicates, was made for subyearling chinook salmon. Turbine Units 3 and 5 were run concurrently with test Turbine Unit 4 during vertical distribution measurements to ensure an even flow into the test unit. Tests began at about 2000 h and lasted 2 to 3 hours. Discharge through each turbine unit was maintained at 16 kcfs throughout the test period.

Fish Guidance Efficiency and Descaling

Methods for testing the extended screens were similar to those used in previous FGE tests with STS (Swan et al. 1987; Brege et al. 1988). A dip basket was used to remove guided fish from the gatewell. A fully netted fyke-net frame in the downstream gate slot was used to collect unguided fish. All nets had cod-ends. The fyke-net catch provided the number of unguided fish. Fish guidance efficiency for each species was calculated as the gatewell catch divided by the total number of fish (by species) entering the turbine intake.

$$FGE = \frac{GW}{GW + FN} \times 100$$

GW = gatewell catch
FN = fyke net catch

Testing with ESTS and ESBS occurred simultaneously in Slots 5B and 6B, respectively. Initial test conditions for the ESTS during the spring out-migration which targeted yearling chinook salmon included a 45%-porosity plate and a fully raised operating gate (ROG). Test conditions for the ESBS included a 30%-porosity plate and an ROG. An ROG is raised and secured sufficiently high in the gate slot to have no effect on the flow up the gatewell and through the vertical barrier screen. Both screens were set at an angle of 55°. Perforated plates with different porosities were required on the two different screens to equalize hydraulic conditions, because of the larger and heavier framework of the ESTS compared to the ESBS. The orifices leading from the gatewell into the fingerling bypass channel were closed during FGE testing. This prevented guided fish from exiting the gatewell and entering the bypass channel, and allowed them to be collected periodically in the dip basket during testing. Tests began about 2000 h and terminated when the number of yearling chinook salmon collected by dip netting Slot 4B indicated that a sufficient number of fish had entered the turbine unit to provide a reliable estimate of FGE. At the end of a test, the turbine units were shut down slowly, the gatewell was dipped, the fyke-net frames were raised from the gate slot, and the catch was removed from each net and placed in individual containers. The catch was enumerated by species and examined for descaling or injuries.

Three FGE test series which targeted subyearling chinook salmon were conducted from 24 June to 25 July during the summer out-migration. The first test series was conducted with a 34%-porosity perforated plate on the ESTS, 30%-porosity perforated plate on the ESBS, a screen angle of 55°, and ROG in both units. The ESBS conditions remained unchanged throughout all test series. During the second test series, the ESTS angle was changed to 62°. During the third test series, the ESTS angle was returned to 55°, but

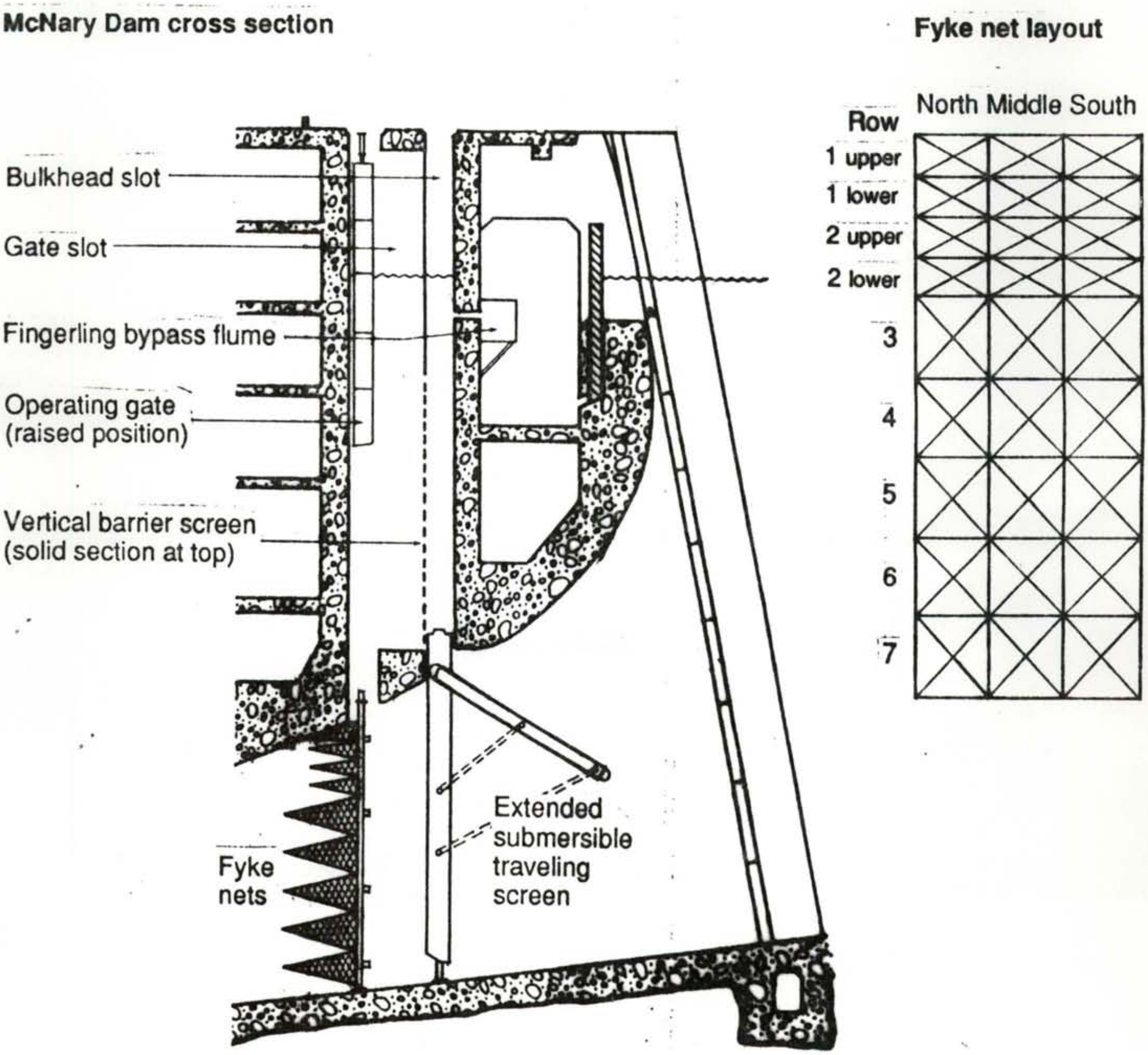

Figure 1. McNary Dam cross section.

flow into the unit was reduced to 12 kcfs. The operating gate for the control STS in Slot 4B was secured so that the bottom of the gate was flush with the ceiling of the intake; this position is defined as a stored operating gate (SOG) by COE.

The quality of fish was measured using standard Fish Transportation Oversight Team (FTOT) fish descaling criteria. Fish from vertical distribution and FGE tests were all examined for descaling.

Results and Discussion

Vertical Distribution Measurements

Yearling chinook salmon had a pooled TFGE of 89.6% during the first series of vertical distribution measurements. During the second series, yearling chinook salmon, steelhead, and sockeye salmon *O. nerka* had pooled TFGEs of 98.6, 97.8, and 91.7%, respectively. The TFGE for the large numbers of subyearling chinook salmon at the beginning of the summer out-migration, 21-23 June, was 97.4%, which was slightly higher than in 1986 during a similar time period (Swan and Norman 1987).

Vertical distribution measurements from the spring and summer indicated that nearly all juvenile salmonids passed through the turbine intakes at a level above the interception point of the extended guidance devices. No vertical distribution measurements were made during the latter part of the subyearling chinook salmon out-migration. A measurement later in the season might have explained the significant decrease in FGE observed during the third week of July, discussed below. In 1987, at McNary Dam, TFGE and FGE of subyearling chinook salmon decreased as the season progressed (Brege et al. 1988). Temporal changes in TFGE and FGE at John Day Dam in 1986 were attributed to varying migrational behavior in the many races making up the subyearling chinook salmon seaward migration (Brege et al. 1987).

Fish Guidance Efficiency and Descaling

Yearling chinook salmon.—Yearling chinook salmon FGE averaged 80.7% for the ESTS and 80.2% for the ESBS during initial tests (Table 1). However, unacceptably high descaling, averaging 19.2% for the ESTS and 11.8% for the ESBS, dictated a redirection of research efforts to determine the cause of the high descaling, so FGE testing was temporarily postponed. We investigated three conditions that we felt could affect descaling: (1) gate position--raised or stored, (2) perforated plate porosity, and (3) an operating gate raised 7.8 ft above the normally stored position. We suspected that excessive flows up the bulkhead slot associated with an ROG contributed to descaling.

An ROG/SOG crossover test series was conducted on 8-13 May in Turbine Unit 5 using ESTS to determine the influence of gate position on descaling. Operating gate positions in Slots 5A and 5B were alternated daily between raised and stored. Identical ESTS (with 45%-porosity perforated plate) were used in both slots. An STS in Slot 4B with an SOG served as the control. The test indicated that the 16.8% average descaling with an ROG was not significantly different from the 14.2% descaling with an SOG, but that descaling on the ESTS was significantly higher than the 8.3% descaling on the STS. We concluded that operating gate position did not affect descaling.

A perforated plate change from 45 to 34% porosity on the ESTS on 17 May significantly decreased the descaling associated with the ESTS from 19.2 to 11.2%, so hydraulic conditions on the screen controlled by perforated plate porosity seemed to affect descaling. The average 9.5% descaling on the ESBS did not differ significantly from the average 13.0% descaling on the STS, even though earlier series indicated some effect of descaling with the ESBS. During the spring out-migration, descaling on the STS in the control slot was highest in mid-May. No changes in porosity of the perforated plate of the ESBS were made during the season.

A descaling test series (22 May-1 June) compared the two extended screen designs functioning with 7.8-ft ROG, an ROG in control Slot 4B, and an SOG in control Slot 7B. Since the spring out-migration was

TABLE 1.—Fish guidance efficiency and descaling for yearling and subyearling chinook salmon at McNary Dam, 1991.

Date	Screen/Conditions[a]	FGE %	Descaling %
Yearling chinook salmon			
4/22-5/5	ESTS, ROG, 55°, 45%	80.7	19.2
	ESBS, ROG, 55°, 30%	80.2	11.8
5/8 -5/13	ESTS, SOG, 45%	[b]	14.2
	ESTS, ROG, 45%		16.8
	STS, SOG, 45% (control)		8.3
5/17-5/21	ESTS, SOG, 34%	[b]	11.2
	ESBS, SOG, 30%		9.5
	STS, SOG, 45% (control)		13.0
5/22-6/1	ESTS, 7.8-ft ROG	[b]	11.0
	ESBS, 7.8-ft ROG		9.9
	STS, ROG (control)		15.5
	STS, SOG (control)		10.7
5/28-6/1	ESTS, 7.8-ft ROG	81.0	
	ESBS, 7.8-ft ROG	73.3	
Subyearling chinook salmon			
6/24-7/2	ESTS, ROG, 55°	74.2	9.3
	ESBS, ROG, 55°	70.1	3.7
	STS, SOG (control)		2.9
7/8-7/14	ESTS, ROG, 62°	70.8	12.3
	ESBS, ROG, 55°	74.8	6.7
	STS, SOG (control)		5.6
7/16-7/25	ESTS, ROG, 55°, 12 kcfs	51.6	11.5
	ESBS, ROG,	53.5	8.2
	STS, SOG (control)		6.1

[a] Standard flow condition, 16 kcfs.
[b] Tests for descaling only.

nearly completed, we evaluated FGE with the 7.8-ft ROG from 28 May to 1 June. The 7.8-ft ROG with the ESTS and the ESBS provided flows up the bulkhead slot equivalent to flows in Slot 4B with the STS and an ROG. The 34%-porosity perforated plate remained on the ESTS. Yearling chinook salmon FGE averaged 81.0% for the ESTS and 73.3% for the ESBS. Descaling averaged 11.0 and 9.9% for the ESTS and ESBS, respectively, with the 7.8-ft ROG, and 10.7% for the STS with an SOG in Slot 7B (control). These descaling values did not differ significantly, supporting the findings of the ROG/SOG crossover series that the ROG had no significant effect on descaling compared to the SOG. Unexpected significantly higher descaling, averaging 15.5%, on the STS with the ROG in Slot 4B compared to the other three slots, was probably due to the standard Vertical Barrier Screen (VBS) in Slot 4B instead of the Modified Balanced Flow VBS in Slots 5B and 6B, since flows up Slots 4B, 5B, and 6B were equivalent.

The FGE with extended screens for yearling chinook salmon ranged from 73.3 to 81.0%; FGEs for the ESBS and ESTS were not significantly different early in the season, but later in the season with a 7.8-ft ROG, the ESTS guided fish significantly better than the ESBS. Yearling chinook salmon descaling was higher on the ESTS than on the ESBS during the spring out-migration, but was significantly higher only early in the season.

Subyearling chinook salmon.—The FGE for subyearling chinook salmon averaged 74.2% for the ESTS and 70.1% for the ESBS during the first test series (24 June- 2 July) (Table 1). Descaling was significantly higher for the ESTS than either the ESBS or STS, averaging 9.3, 3.7, and 2.9%, respectively.

In an attempt to reduce descaling, for the second FGE test series (8-14 July) the ESTS screen angle was changed from 55° to 62°, to reduce the area of flow intercepted by the screen and thereby decrease the velocity through the screen. The ESBS screen angle remained unchanged at 55°. Fish guidance efficiencies remained high and averaged 70.8 and 74.8% for the ESTS and ESBS, respectively. Descaling of subyearling chinook salmon on the ESTS set at 62° was again significantly higher, averaging 12.3%, than on the ESBS and the STS, where descaling averaged 6.7 and 5.6%, respectively.

Since descaling was not reduced on the ESTS with a screen angle of 62°, the final test series (16-25 July) for subyearling chinook salmon was conducted with the ESTS at 55° but with a reduced flow of 12 kcfs through Turbine Unit 5, in another attempt to reduce descaling with the ESTS. Flow through Turbine Unit 6 with the ESBS remained unchanged at 16 kcfs. The FGE decreased significantly from the previous test series on both screens and averaged 51.6% and 53.5% for the ESTS and ESBS, respectively. Descaling with the ESTS was still high, but not significantly different from the ESBS or STS, and averaged 11.5, 8.2, and 6.1%, respectively. Descaling did not differ significantly between the ESBS and STS in any of the three test series with subyearling chinook salmon, averaging 6.2 and 4.9%, respectively. Furthermore, we found no significant differences in FGE between the ESTS and the ESBS for the three sets of test conditions. The dramatic decrease in FGE in mid-July was also observed by researchers at Wanapum Dam on the mid-Columbia River (Stuart Hammond, Grant County PUD, Ephrata, Washington. Personal communication), and may be a response of subyearling chinook salmon to changing physiological or environmental conditions such as increasing water temperature, which could alter vertical distribution.

Summary

Vertical distribution measurements indicated that extended-length screens should guide nearly all juvenile salmonid out-migrants.

For yearling chinook salmon, fish guidance efficiency at McNary Dam in 1991 was about the same with the ESTS and ESBS during the early season tests, but later in the season, with a 7.8-ft raised operating gate, the ESTS had significantly higher FGE than the ESBS. However, the ESTS showed higher descaling compared to the ESBS, and sometimes when compared to the STS. Gate position did not appear to affect descaling on the ESTS. Reducing plate porosity eliminated the significant difference in descaling between the ESTS, the ESBS, and the STS. There was no significant difference in descaling with a 7.8-ft raised operating gate.

For subyearling chinook salmon, FGE was higher with extended length screens than previously observed with standard length screens. During the third test series, FGE decreased but was still greater than the basin-wide average of 35%. FGE did not differ significantly between the ESTS and the ESBS. Descaling was significantly greater on the ESTS than on the ESBS and STS except when flow through the turbine was reduced, simulating a reduced approach velocity to the screen.

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The Vulnerability of Juvenile Chinook Salmon to Predation by Northern Squawfish

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Northern squawfish are major predators of juvenile salmonids in the Columbia River (Poe et al. 1991). However, the overall significance of predation as a mortality factor remains a question if prey in poor condition are selected for or are more vulnerable to predation. In the Columbia River, out-migrating juvenile salmonids can encounter several dams and are stressed, descaled, or even killed while passing through turbines, spillways, and bypasses (Kostecki et al. 1987; Maule et al. 1988). Northern squawfish predation rates are highest near dams, either because of high concentrations of prey there or because prey may show deficits in predator avoidance ability due to passage-related stress or injuries. Consequently, we compared predation rates on control fish versus three categories of "substandard" juvenile salmonids: dead (Gadomski and Hall-Griswold, in press), descaled, and stressed.

Concern over the decline of many stocks of Pacific salmon has led to efforts aimed at increasing juvenile salmonid survival, including a reduction in predation-related mortality. One general method of protecting outmigrating juvenile salmonids that is receiving much attention concerns the location and construction of new bypass facilities, and the alteration of existing ones. Because northern squawfish seemingly prefer low water velocities near bypass outlets (Faler et al. 1988), there is the possibility of using high water velocities to exclude or reduce the efficiency of predators near bypass outfalls. We addressed this question by determining the performance of northern squawfish at prolonged swimming speeds, i.e., those speeds that a fish can maintain for ≤ 200 min and typically end in fatigue (Beamish 1978).

Methods

Predation Experiments

Subyearling spring chinook salmon were used as prey and northern squawfish were used as predators for all experiments. All fish were maintained in either 1400-L circular tanks or an 11,300-L flowing water raceway under ambient water temperature and photoperiod. Prior to all experiments, some chinook salmon were marked to facilitate the identification of treatment and control fish.

A group of prey designated as treatment fish were subjected to one of several treatments: They were either (1) killed by a blow to the head, (2) descaled on either 10 or 20% of their total body area, (3) subjected to three 30-s handlings, each 1 h apart; or (4) subjected to three 5-min agitation stresses, each 0.5 h apart. Equal numbers of treatment and control fish were simultaneously released into either the circular tanks or the raceway containing predators. Predation occurred under different photoperiods and was allowed to proceed for various lengths of time (from less than 1 h to 24 h), depending on the experiment. At the end of all experiments, surviving prey were netted from the tanks and identified. Chi-square goodness-of-fit tests were used on pooled data from several replicates to determine if feeding was random (i.e., 50:50).

For the live vs. dead experiments, we also released large numbers of coded wire-tagged (CWT) prey into the tailrace of Bonneville Dam. Northern squawfish were collected by boat electroshocking after the release of prey and their stomachs examined for the presence of CWT prey.

Swimming Performance Tests

The prolonged swimming performance of northern squawfish was measured in a large stamina tunnel at 12°C and 18°C for medium-size (30-39 cm fork length; FL) and large-size (40-49 cm FL) fish. A single fish was netted from an acclimation tank, rapidly measured to the nearest cm, and placed into the swim chamber. Fish were acclimated for 30 min at a water velocity of 0.75 fork lengths per second (FL/s).

Following the acclimation period, the water velocity was gradually increased over about 5 min to a selected test velocity. Selected test velocities were determined from preliminary experiments designed to find a range of velocities over which the percentage of fish fatigued varied from 0 to 100% in 120 min. Fish were tested for 120 min or until fatigued; sample size varied at each test velocity. Following a test, fish were removed, sacrificed, weighed to the nearest 25 g, and sexed. We used a "dose-response" curve to describe the relation between percentage fatigued and velocity for both size groups (Brett 1967). Because our curves were not complete, we estimated FV_{50} values (the velocity at which 50% of the fish fatigued) and maximum prolonged performance using graphical interpolation.

Results and Discussion

Predation Experiments

Northern squawfish ate significantly ($P < 0.05$) more dead than live prey under all experimental conditions (Figure 1). Dead prey are not commonly reported to be eaten by fish; moreover, for many fish prey movement appears to be an important feeding cue (Howick and O'Brien 1983; Irvine and Northcote 1983). In contrast, descaled and control prey were eaten in roughly equal proportions during all experiments. Although the experimental descaling of juvenile salmonids did not result in enhanced risk of predation, the effects of descaling on fish in the wild may be more serious than is evident from laboratory studies alone. In addition to descaling, fish may be exposed to a number of other stressful conditions that could have more severe, cumulative effects.

Juvenile salmon exposed to multiple handling stresses did not differ significantly from controls in their vulnerability to predation, irrespective of the time fish were exposed to predators (Figure 2). When juvenile salmon were exposed to multiple agitation stresses, however, they were significantly more vulnerable to predation for up to 90 min (Figure 3).

The notion that multiple stresses should have more pronounced and longer lasting effects on predator avoidance seems intuitively acceptable and is implicit in some studies (Maule et al. 1988; Sigismondi and Weber 1988), yet was only apparent in fish subjected to the agitation procedure.

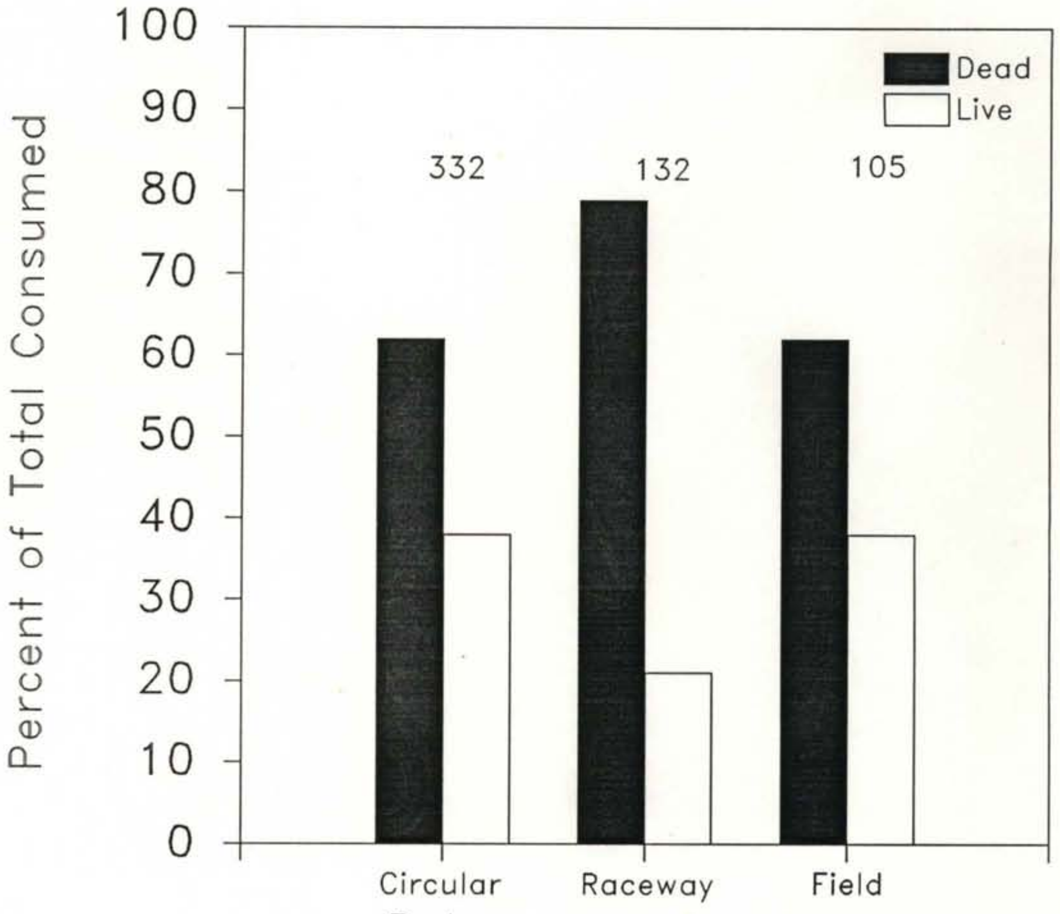
Collectively, our results suggest that deficits in predator avoidance are short lived and dependent on the severity of the treatment and the predator-prey system being studied. Our results are most relevant to predator-prey interactions in dam tailrace areas, although it is conceivable that differential predation may occur reservoir-wide. Since northern squawfish ate significantly more dead salmon and salmon subjected to multiple agitation stresses, fewer healthy fish may be eaten in the field than previously assumed.

Swimming Performance Tests

Northern squawfish fatigued faster at 12°C than at 18°C, irrespective of size (Figure 4). The estimated FV_{50} values were 10-12 cm/s lower at 12°C than at 18°C. Estimated maximum performance ranged from about 107-112 cm/s for medium-size fish and from 118-135 cm/s for large-size fish, depending on temperature. Our results, although incomplete, suggest that using high water velocities to exclude or reduce predation by northern squawfish near juvenile salmonid bypass outlets at Columbia River dams seems promising, at least during the spring and early summer. We estimate that northern squawfish would not be able to hold position at water velocities above 150 cm/s in water temperatures up to 18°C. We recommend the that new bypass facilities be constructed, or existing ones modified, to maximize the area of high water velocity around the outlet and minimize eddies and submerged cover, and that they be located away from littoral areas.

Figure 1

FIGURE 1.—The percentage of dead and living fish in the total number of juvenile chinook salmon eaten by northern squawfish. The numbers above each pair of bars are the total number of fish consumed, all replicates combined, in three different experimental arenas.



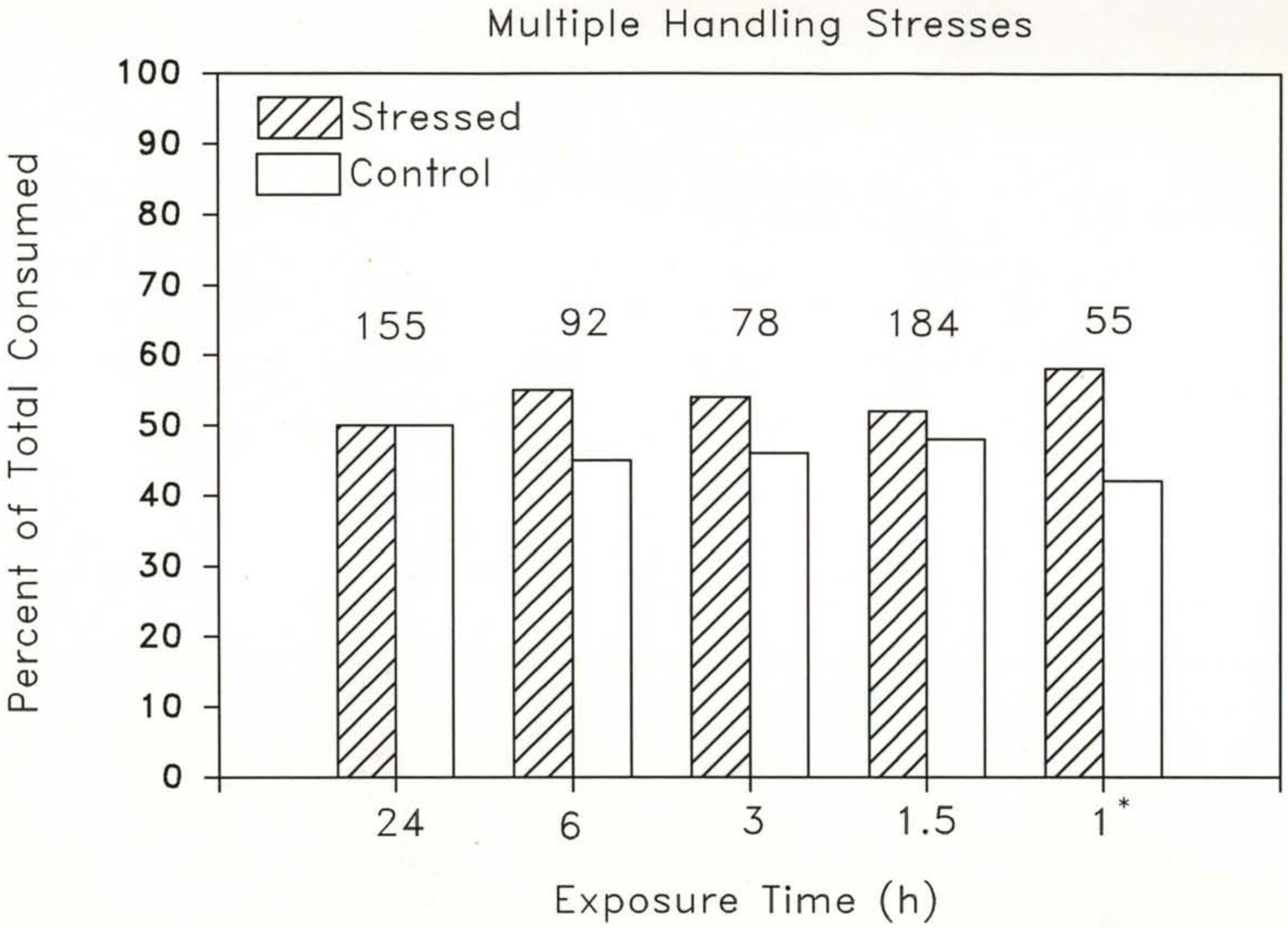


FIGURE 2.—The percentage of control fish and fish that were stressed by three 30-s handlings in the total number of juvenile chinook salmon eaten by northern squawfish. The numbers above each pair of bars are the total number of fish consumed, all replicates combined. The asterisk denotes that these experiments ran until about 30-50% of the prey were consumed, or for 1 h.

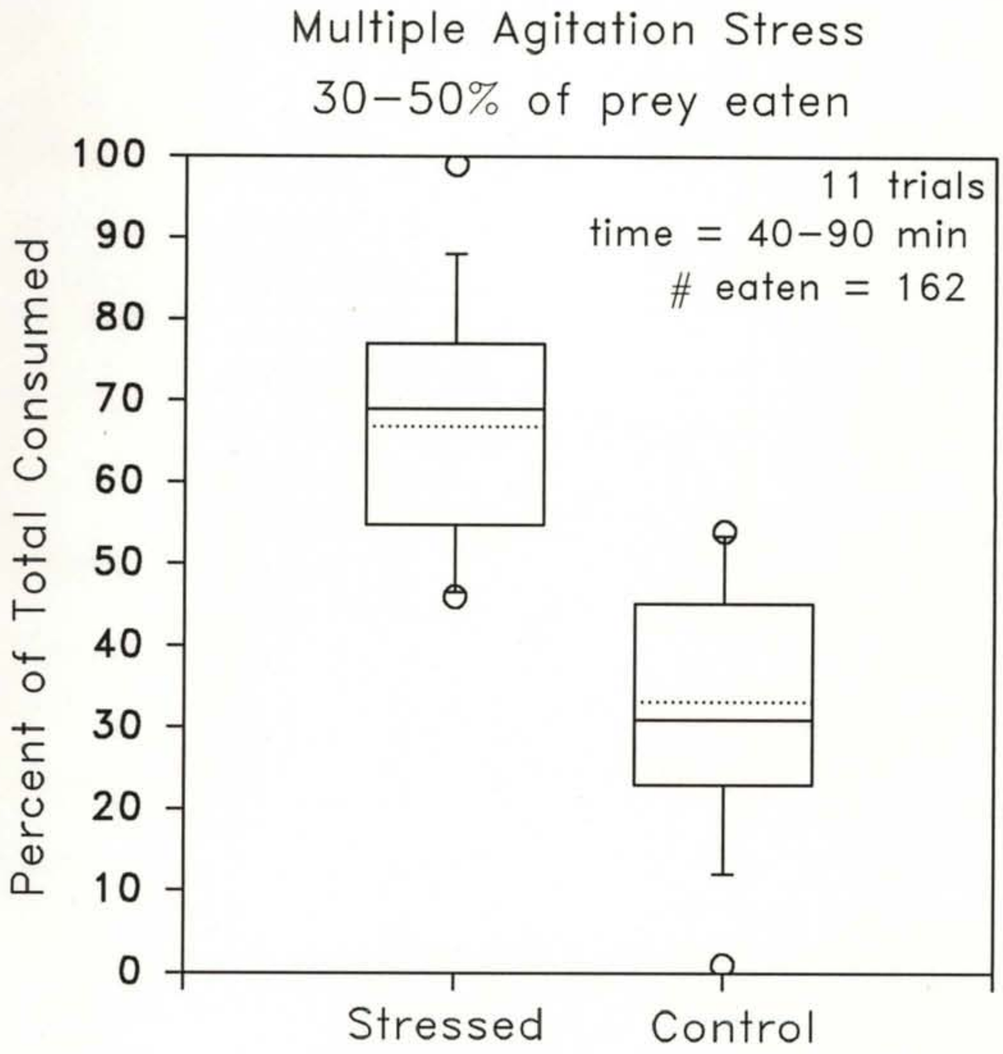


FIGURE 3.—The percentage of control fish and fish that were stressed by three 5-min agitations in the total number of juvenile chinook salmon eaten by northern squawfish. Mean (dotted line), median (solid line), and range (open circles) are combined data from 11 trials. Trials ran until about 30-50% of the prey were consumed, or for up to 90 min.

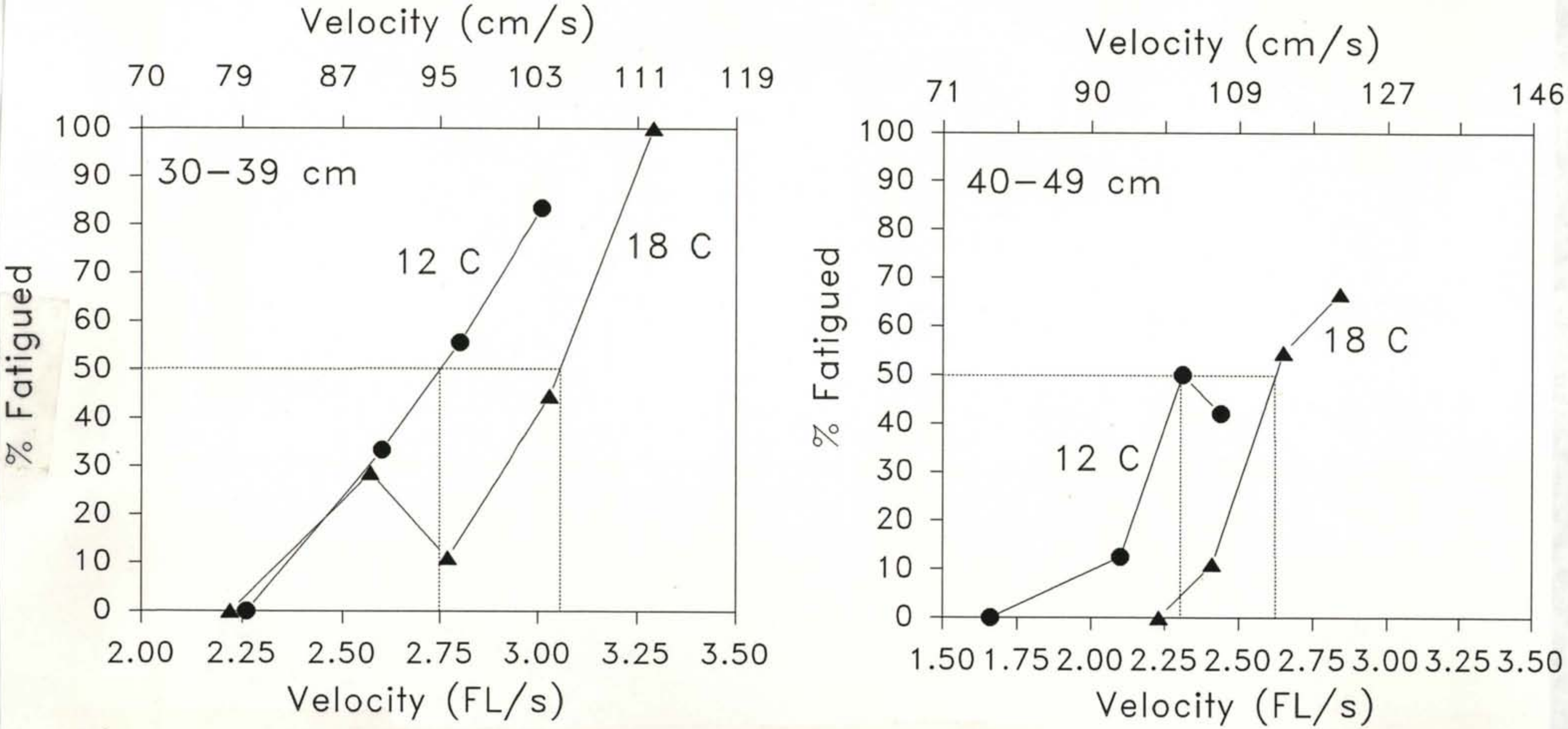


FIGURE 4.—The relation between percentage of fatigued fish and water velocity at 12 and 18°C for two sizes of northern squawfish. The 120 min FV_{50}, or velocity at which 50% of the fish were fatigued in 120 min, is estimated by the dashed lines.

Summary

1. Northern squawfish consumed more dead than live juvenile salmonids under all experimental conditions.

2. Experimental descaling of juvenile salmon on 10 or 20% of their total body area did not result in enhanced risk of predation.
3. Stress-induced deficits in predator avoidance were short lived and apparently dependent on the severity of the stress.

4. The maximum prolonged swimming performance of northern squawfish was estimated at 150 cm/s and was affected by fish size and water temperature.

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An Overview of Twenty Years of Research on Transportation of Yearling Chinook Salmon Smolts

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Introduction

In 1968, the National Marine Fisheries Service began extensive studies on the effects of transporting steelhead *Oncorhynchus mykiss* and yearling chinook salmon *O. tshawytscha* smolts from Ice Harbor Dam to below Bonneville Dam as a means of avoiding the deleterious effects of passage through the hydroelectric dams and reservoirs (Figure 1). Marking juvenile fish for evaluation continued at Little Goose and/or Lower Granite Dams from 1971 through 1980 and again at Lower Granite Dam in 1986 and 1989. On the Columbia River, the effects of transportation were evaluated by marking steelhead and subyearling and yearling chinook salmon at McNary Dam from 1978 through 1983. Chinook salmon studies were repeated from 1986 through 1988. Juvenile sockeye salmon *O. nerka* and yearling chinook salmon were marked for transportation studies at Priest Rapids Dam between 1984 and 1986. Sockeye salmon studies continued through 1988. Few, if any, experimental studies on the Columbia River have received more intense scrutiny over such a protracted period.

Mark/recapture methods have been, and continue to be, the principal tools for evaluating transportation of juvenile salmonids. Groups of out-migrant juvenile salmonids collected at an upstream dam receive distinctive coded-wire tags and freeze brands. One group is then transported and released below Bonneville Dam while the other is returned to the river as an experimental control to continue the downstream migration through the hydropower complex. Adult recoveries from ocean and river fisheries, fish ladders at dams, hatcheries, and spawning grounds are compared between experimental groups and expressed as a transport-to-control ratio (T/C) to evaluate the effectiveness of the technique. The T/Cs also provide indirect information on the effect transportation has on the homing ability of returning adults. If no differential mortality occurs between groups, a steadily decreasing T/C from marked adults sampled as they progress upstream implies a loss of homing ability. Homing impairment would also be indicated if excessive numbers of adults returned to inappropriate locations (straying).

The effects of transportation on anadromous salmonid populations can also be examined indirectly by observing trends in abundance over time for populations that have been extensively (mass) transported. This type of analysis must be viewed in perspective because other factors besides transportation can affect population abundance, particularly short-term trends in abundance. Examples are annual variations in ocean survival, ocean and freshwater fisheries, and freshwater environmental conditions that can influence survival over both periods of freshwater residency. Severe annual drought or extended drought are examples of the latter. Also, transportation has been used extensively for only about two to four generations of fish, depending upon the species. This is a relatively short period, considering both the depressed status of all stocks at the time that mass transportation of smolts was initiated, and the potential for stochastic processes, unrelated to smolt transportation, to negatively impact small populations in the short term.

In this paper, I review the studies evaluating transportation as a means to increase survival of yearling chinook salmon smolts. Results of annual research, effects of juvenile transportation on the homing ability of adults, and the overall response to mass transportation are discussed.

Overview of Research

On the basis of adult returns, the results of the transportation studies varied by species. For steelhead and summer/fall chinook salmon, the latter migrating as subyearlings, tag return information from transportation research indicated consistently and conclusively that the process was beneficial for these stocks. This has

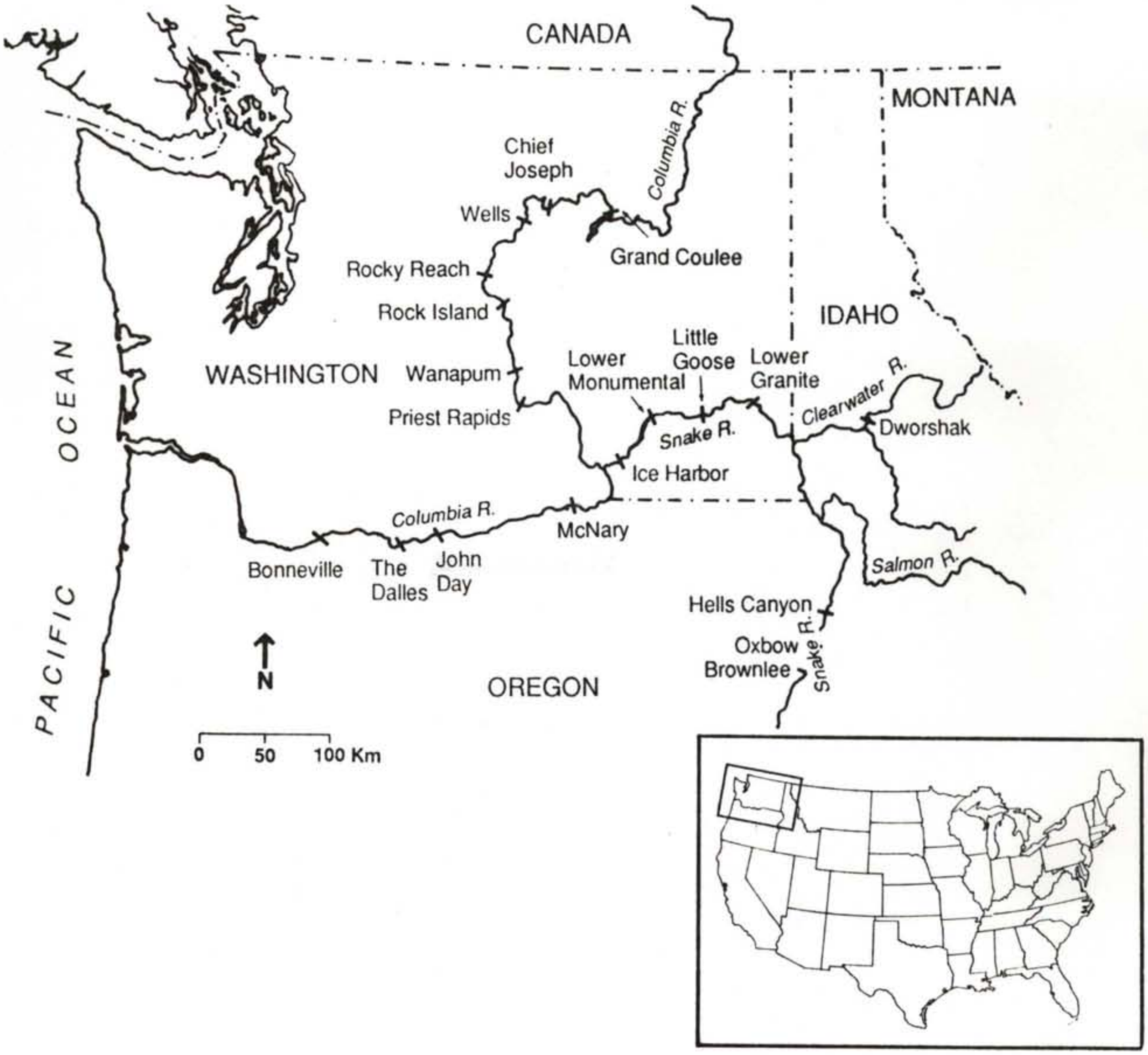

Figure 1. Map of study area showing locations of dams on the Columbia and Snake Rivers.

resulted in a management strategy of maximizing transportation of these stocks under all environmental conditions. For sockeye salmon, transportation studies were inconclusive. This resulted primarily from difficulties in collecting adequate numbers of juveniles for marking, and possibly also from problems at the transport release site. For spring/summer chinook salmon, migrating as yearling smolts, study results were less consistent, with earlier studies indicating a significant benefit and later studies producing inconclusive results due to poor adult returns. This scenario has resulted in a controversial management strategy for this stock which has been termed "spread the risk." Basically, this means that all smolts collected at Lower Granite, Little Goose, and McNary dams are transported when river flows are below a certain level. When flows are above this level, only smolts collected at Lower Granite Dam are transported. Those collected at the other two dams are returned to the river to continue their migration through the hydropower complex. Why the earlier study results indicated a significant benefit and the later studies were inconclusive is of interest and concern.

From 1968 through 1980, 24 separate transportation studies were conducted at dams on the Snake River using spring/summer chinook salmon as the target species (Ebel et al. 1973; Slatick et al. 1975; Ebel 1980; Park 1985; Chapman et al. 1991). Studies were conducted at Ice Harbor Dam in 1968-70, at Little Goose Dam in 1971-73 and again in 1976-78, and at Lower Granite Dam in 1975-80. A few additional studies were attempted on the Columbia River at McNary Dam in 1978-80 and at Priest Rapids Dam in 1984-86, but results were inconclusive due to insufficient adult returns. Both truck and barge transport were tested. In a few of the truck tests, a saltwater transport medium was tested, but results were inconclusive due to poor adult returns. In 10 of the 24 (42%) Snake River tests, significantly more transported than control fish were recovered as returning adults from traps in the fish ladders at dams where the studies originated. In five of the tests, more, but not significantly more, transported than control fish were recovered as adults in the traps. In another five of the tests, returns of both groups were so low that results were meaningless. In two tests (1977), no fish of either group returned. In two tests (1976), Park (1985, considered as one test) reported that significantly more control than transported fish were recovered as adults. However, adult returns from two truck transport release sites had been combined to provide sufficient values for statistical analysis. The intent of the study was to compare the two release sites with each other as well as each with the control. If the data had been treated in this way, as I believe is appropriate, then the adult return rates for each group were too low for meaningful comparisons. Over the course of these 24 studies, T/Cs ranged between 0.7 and 18.1. The three studies reporting T/Cs below 1.0 were associated with extremely poor adult returns of both experimental groups, resulting in insufficient returns for analysis or nonsignificant differences in the returns.

Marking of barge-transport-only groups was reinitiated at Lower Granite Dam from 1983 through 1985. In-river controls, released below Little Goose Dam, were included in 1986 and 1989 (Matthews et al. 1990). Adult returns for the 1986 study year are complete with a T/C estimate at the dam of 1.6 and a 95% CI of (1.01, 2.47). While adult returns for the 1989 study year are incomplete, the T/C is currently 2.5 (Updated January, 1993)..

Although more or significantly more transported than control fish returned as adults in most of the studies conducted from 1968 through 1980, there is a reluctance for fisheries managers to fully endorse transportation of spring/summer chinook salmon. This reluctance apparently relates to the decline in the adult return rates of transport and control groups through time. This was probably due to a difference in the composition of fish within the population during the later studies, and a deterioration of the condition of study fish due to poor collection and handling procedures as detailed below.

The first study to evaluate the transportation of Snake River spring/summer chinook salmon was conducted at Ice Harbor Dam in 1968 by Ebel et al. (1973). Smolts were dipped directly from unscreened gatewells, marked as appropriate, and either transported by truck to below Bonneville Dam or released as controls above the dam. Significantly more transported than control fish returned to the dam as adults. The observed (sampled) adult return rate was 0.14% for the control group and 0.30% for the transported group resulting in a T/C of 2.0. By retagging all observed adults at the dam and subsequently examining the hatchery and wild populations after spawning, the investigators estimated total adult returns of 4.3% for the control group and 9.0% for the transported group. According to Raymond (1988), the 1968 smolt outmigration was composed of nearly 80% wild fish, and the smolts originating from the only hatchery (Rapid River Hatchery) returned as adults nearly as well as the wild fish.

The study was repeated at Ice Harbor Dam in 1969 and 1970 with significantly more transported fish returning to the dam as adults than controls for both study years (Slatick et al. 1975). The T/Cs were 1.3 and 1.5 for the 2 years, respectively. Again, the population had a higher abundance of wild than hatchery fish and both had a high survival to adulthood (Raymond 1988). However, while the observed adult return rates were similar to the rates observed for the 1968 study, the estimated total returns for both groups of study fish were much lower. During these two study years, smolts were not dipped from the gatewells prior to marking as in 1968; instead, an orifice/wooden flume bypass system, installed in the ice and trash sluiceway, was used to collect smolts for marking. An inclined-screen trap was located at the terminus of the flume and was used to collect and hold fish. A fish pump was incorporated into the system to pump the smolts against 15 m of hydraulic head to the intake deck for marking. Also, smolts had to pass through one or two new dams (Lower Monumental Dam, completed in 1969, and Little Goose Dam, completed in 1970) before arriving at Ice Harbor Dam. Slatick et al. (1975) reported a high incidence of gas bubble disease in smolts collected for marking at Ice Harbor Dam in 1969 and 1970, due to spilling excess flow at either or both upstream dams in 1969 and 1970. These operational differences resulted in smolts in poorer physical condition for the experimental groups compared to 1968. This, I believe, was the first indication of one of two principal reasons that adult return rates of study fish deteriorated drastically--the level of physical trauma suffered by smolts in both experimental groups progressively increased.

Beginning in 1971 and continuing through 1978, transportation research was conducted at Little Goose Dam. The experimental fish were marked after they had been diverted from turbine intakes by submerged travelling screens, passed through an orifice bypass system, and shunted through a fish and debris separator into collection raceways (Smith and Farr 1975). A fish pump was again used to move fish from the collection raceways into the sorting and marking building. Adult return rates for the first year were similar to those observed at Ice Harbor Dam in 1969 and 1970 (Ebel 1980). Significantly more adults returned to the dam from two separate groups that were transported as juveniles by truck than from the control group, with T/Cs of approximately 1.6 for both transported groups. Based upon descaling and delayed mortality measurements, Ebel (1980) reported that poorer fish condition at the time of release was most likely a major factor contributing to the lower adult return rates for study fish during the earlier studies at Little Goose Dam as compared to the original study at Ice Harbor Dam in 1968.

In 1972, adult return rates suddenly plummeted (Ebel 1980). More adults returned from the transported than from the control groups, but the differences were not significant. In 1973, the study coincided with a period of severe drought and attendant low river flows. Significantly more adults returned from the two transported groups than from the control. The T/Cs for the two tests were 13.5 and 18.1. From 1976 through 1978, truck transportation research continued at Little Goose Dam. Adult return rates for both study groups continued to be very poor, resulting in inconclusive results for all 3 years.

As the transportation research continued at Little Goose Dam, additional research began upstream in 1975 at the newly constructed Lower Granite Dam. A complete juvenile fish diversion, bypass, and fish-holding system was incorporated during construction of this dam (Matthews et al. 1977). The new system utilized only gravity-flow to transfer fish, and it was hoped that this would help alleviate much of the physical trauma experienced by fish in the system at Little Goose Dam. However, at Lower Granite Dam during the late 1970s, a massive wood debris accumulation in the forebay continually clogged trash racks (Smith et al. 1980) and accumulated in the gatewells and fish facility. Gatewell orifices were obstructed by this material as were all other components of the collection system. Also, the fish separator was a "dry" type typical of earlier models. Today's models are of the "wet" design with submerged grader bars. Debris accumulated between the exposed grader bars of the older models. In addition, the plumbing in the system was undersized for transferring fish safely and expeditiously and was highly susceptible to partial or complete blockage by debris. For example, during peak collection periods, it typically required 1 hour, and at times up to 3 hours, to transfer fish from one of the five raceways into a fish transport barge. Occasionally, the

6-inch transfer lines would completely plug with debris. It was not unusual for the system mortality rate to be so high that precise enumeration was impossible--counts were often attempted by estimating the number of smolts in full or partially full dip nets of fish removed from the raceway tailscreens. During the first year of study in 1975, results were similar to earlier results at Ice Harbor Dam during 1969-70 and at Little Goose Dam in 1971. Nevertheless, from 1976 until the Lower Granite Dam studies were completed in 1980, adult return rates for both study groups were poor. Even so, in 1978 and 1979, significantly more adults returned from both truck and barge transported groups than from the corresponding control groups. In retrospect, considering the detrimental effects of collection in terms of physical trauma and the apparently low capacity for survival of hatchery fish, it is remarkable that any study fish returned as adults during this period.

The progressive deterioration of adult return rates also coincided with a second major factor. In 1969, more than 80% of the smolts were of wild origin, but this dropped to approximately 50% between 1970 and 1974 (Raymond 1988). Furthermore, between 1975 and 1980 the composition of wild fish in the population ranged between 48 and 26%. Although adult return rates for hatchery and wild fish in the general population remained high in 1970 and 1971, in 1972, coincidental with the sudden decline of adult returns of study fish in the experimental groups at Little Goose Dam, adult return rates of fish in the general population suddenly declined, with the hatchery portion about sevenfold lower than the average of the previous 5 years (Raymond 1988). With the exception of 1975, adult return rates of fish in the general population continued to decline or remained substantially below previous levels through the late 1970s, with the hatchery return rate considerably lower than that of the wild stocks. It has been noted elsewhere that as hatchery production increased through time in the Columbia River basin, the return rate of adults decreased (McIntyre 1987; Chapman et al. 1991).

From 1981 through 1984, the U.S. Army Corps of Engineers and fisheries agencies took major steps to correct the problems in the smolt collection systems at dams, particularly at Lower Granite Dam. Since then, additional improvements have been incorporated into the systems annually. Moreover, the pre-anesthesia system of handling and marking smolts (Matthews et al. 1986) was introduced at Lower Granite Dam in 1983 and at McNary Dam in 1987. This system virtually eliminated the major physical traumas associated with the handling and marking process. All indications suggest that the modifications and improvements substantially increased survival. For example, at Lower Granite Dam, Matthews et al. (1988) reported an average tenfold decrease in post-marking delayed mortality rates for spring/summer chinook salmon smolts from 1983 through 1986 as compared to the average from 1976 through 1980. Furthermore, in contrast to results from earlier studies, delayed mortalities for spring/summer chinook salmon smolts were lower than for steelhead smolts. Major improvements in the observed adult return rates of marked and transported fish also occurred. Compared to the returns in earlier study years noted above, observed adult returns to the dam were four to seven times higher for the 1983 through 1985 study years. This was despite the fact that, relative to the 1976 through 1980 study years, the smolt populations of the most recent years had higher percentages of the poorer surviving hatchery component (Raymond 1988).

Homing Behavior

Impairment of homing behavior in returning adult spring/summer chinook salmon that were previously transported as smolts was not detected during the 1968-70 Ice Harbor Dam and 1971-73 Little Goose Dam studies (Ebel et al. 1973; Slatick et al. 1975; Ebel 1980; Park 1985). During all studies, the T/Cs for spring/summer chinook salmon at the hatcheries and on spawning grounds were either equal to or higher than those at the downstream dams. More recently, adult returns for the study conducted at Lower Granite Dam in 1986 have been completed. Although too few adults were recovered from the hatcheries or spawning grounds to allow meaningful statistical comparisons with the T/C estimate at Lower Granite Dam, it is worth noting that at Rapid River Hatchery, where the largest number of study fish was recovered (26), the T/C was higher than at Lower Granite Dam (Matthews et al. 1990).

No incidents of straying were reported for the Ice Harbor Dam studies (Ebel et al. 1973; Slatick et al. 1975). For the 1971-73 Little Goose Dam studies, 10 adults from the transported groups and 2 from the control groups were recovered at Pelton Dam on the Deschutes River (Ebel 1980). Nevertheless, 857 adults from the same test groups were identified at Little Goose Dam. Park (1985) identified as strays 11 of 1,182 returning adult spring/summer chinook salmon that were transported as juveniles from Lower Granite, Little Goose, and McNary Dams from 1975 through 1980. All strays were recovered in the Deschutes River and none of the strays were from the studies conducted at McNary Dam. To date, in the most recent studies at Lower Granite Dam (1983-89), 13 (10 were recovered from the Deschutes River) of 824 recovered adult spring/summer chinook salmon that were transported as juveniles have been identified as strays. These incidents of straying are generally fewer than the incidents of straying of anadromous salmonids reported elsewhere (Chapman et al. 1991).

During the last decade, millions of spring/summer chinook salmon juveniles were coded-wire-tagged at hatcheries in the Snake River drainage. Even though many of these smolts were transported to below Bonneville Dam during this period, only two returning adults were recovered at unexpected locations (Chapman et al. 1991). A localized incident of straying was also reported in the Grande Ronde River drainage in recent years (Chapman et al. 1991); several adults released as juveniles at Lookingglass Creek Hatchery were recovered from two nearby streams. Incidents such as this are rare and may not have any relationship to transportation as smolts.

Mass Transportation

Mass transportation of spring/summer chinook salmon smolts was initiated at Lower Granite and Little Goose Dams in 1976. In the first year, only 15% of the estimated smolt population arriving at Lower Granite Dam was transported from both dams combined to below Bonneville Dam (Koski et al. 1986). From 1977 through 1985, an average of 47% (ranging from 26% to 68%) of the estimated annual smolt populations arriving at Lower Granite Dam was transported from both dams combined. Since 1985, the annual abundance of smolts arriving at Lower Granite Dam has not been estimated. However, hatchery production has nearly doubled since then, and the numbers transported have steadily increased.

Demonstrating the positive influence of mass transportation on the general population of Snake River spring/summer chinook salmon, in contrast to steelhead populations, is problematic. This is particularly true if only total adult returns to the river (dam counts, which include both hatchery and wild fish) are considered. For example, from 1975 through 1978, annual adult returns (including jacks) averaged 39,204 fish at Lower Granite Dam. Over the next 6 years (1979 through 1984) counts declined considerably, averaging only 16,932 fish and including the lowest returns on record of 11,111 and 10,205 fish in 1979 and 1980, respectively. I believe that these poor returns were primarily attributable to the previously described problems associated with the smolt collection systems at dams during this period and the devastating impact of the 1977 drought. After the major modifications and improvements were incorporated into the smolt collection systems in the early 1980s, annual adult counts improved to an average of 31,268 fish from 1985 through 1988. During the last 3 years (1989 through 1991), however, annual adult counts declined again, averaging 17,975 fish. Considering the total number of spring/summer chinook salmon smolts that were transported over the last 11 years, these return statistics are unimpressive. However, hatchery production roughly doubled during the early 1980s and then roughly doubled again since 1987. At the same time, the abundance of wild fish in the population was the lowest in history (Matthews and Waples 1991). Therefore, the totals transported were increasingly dominated by fish with dubious survivability, regardless of any influence from smolt transportation. Perhaps more important was the fact that wild populations were at such low levels of abundance at the beginning of the decade that even a relatively good response by wild fish might be obscured within dam counts of the composite population.

Redd counts in index areas provide the best indicator of trends in abundance of wild fish in the Snake River Basin (Matthews and Waples 1991). Since redd counts were initiated in the late 1950s, trends in all areas have followed the same basic pattern. For simplicity, I focus on redd counts in the Middle Fork of the Salmon River--a primary production area for wild spring chinook salmon in Idaho. I examined the temporal trend in redd production in this drainage as a redd recruit per redd ratio (R2/R1) progressing through 5-year population segments (roughly, generations). The R2/R1 is the total number of redds counted in a 5-year period (R1) divided into the total redds counted in the next 5-year period (R2). From 1960 through 1979, the R2/R1 declined steadily through four reproductive cycles of salmon (White and Cochnauer 1989). For the successive generations the R2/R1s were 0.8, 0.6, 0.5, and 0.3. However, the R2/R1 for the 1980-84 generation increased dramatically to 3.4. Smolts of this generation migrated downstream from 1982 through 1986 and returned as adults from 1984 through 1988. The smolt migration period coincided with the major modifications and improvements in the smolt collection systems at dams. Particularly impressive was the performance of wild smolts in the 1985 out-migration. In that year, Koski et al. (1986) estimated that over 50% of the smolts arriving at Lower Granite Dam were transported. Fish from this out-migration predominated the ensuing adult returns as 2-ocean fish in 1987 and 3-ocean fish in 1988 (Fryer and Schwartzberg 1991). In the latter year, the total redd count in the Snake River drainage was the highest since 1978 and, in the Middle Fork of the Salmon River, the highest since 1973 (Matthews and Waples 1991). It is noteworthy that river flows in the Snake River during the spring and early summer of 1985 were the lowest of the 5-year period 1982-86 (USACE 1985) and would be considered somewhat below average.

Adult returns are incomplete for the most recent reproductive cycle (1985-89); however, returns to date indicate that the R2/R1 will again fall somewhat below 1.0 for that generation. Several complicating factors, unrelated to smolt transportation, may be negatively impacting this most recent generation of wild fish. Since 1987, the Snake River drainage has been in an extended period of drought characterized by minimal snowpacks and periods of extreme mid-winter cold. Water discharge from all streams has been reduced substantially. These types of severe environmental conditions are known to negatively impact the survival of juvenile salmonids in freshwater ecosystems (Edmunson et al. 1968; Seelbach 1987). In addition, as previously mentioned, hatchery production increased substantially beginning in 1987. Chapman et al. (1991) provided a meticulous review of the potential adverse impacts of hatchery fish on wild populations. Yet, progressively more were released and production is scheduled to increase even more in the near future. Finally, the 1989 out-migration of both spring/summer chinook salmon and steelhead survived very poorly. Recent adult return rates of both transport and control groups of both spring/summer chinook salmon and steelhead from this out-migration year were well below the expected return rates, as were the populations in general for both species. This suggests that the 1989 out-migrations of both species survived poorly during their first year after passage through the river, regardless of transportation. It is also noteworthy that river flows in the Snake River in the spring/summer of 1989 were the highest of the past 5 years and were very similar to flows in 1985--the year that produced the highest adult return of wild fish since the mid-1970s.

Discussion and Conclusion

Transportation research conducted from 1968 through 1980 was less successful overall for yearling chinook salmon smolts than for other anadromous salmonid stocks. This was due to a marked decrease in the adult return rates of study fish of both test groups during this time. A shift in the structure of the population from one dominated by wild fish to one dominated by more poorly surviving hatchery fish, and an increase in the physical trauma suffered by smolts during collection, were responsible for the decrease in adult return rates. Nevertheless, in nearly all tests, more or significantly more adults returned from the transported than from the nontransported groups. Complete returns for the most recent study year (1986) showed that significantly more transported fish than nontransported fish returned as adults.

Recently, mathematical modeling of the 1986 study results suggested that transportation may not maximally benefit spring/summer chinook salmon smolts (McConnaha 1991). Under a typical scenario, mortality was calculated at 15% per project for in-river controls under average conditions. This led to the conclusion that if 100% of the transported fish had survived relative to the in-river controls released below Little Goose Dam, the T/C should have been 3.1 rather than the measured 1.6. If the computer modeling results represent the true in-river survival conditions, the computer results implied that transported fish incurred an approximate 50% additional mortality relative to the controls. Furthermore, the computer modeling implies that no benefit would be gained from transportation at McNary Dam if the T/C from Little Goose Dam was only 1.6.

In developing the model for this analysis, the various factors affecting juvenile migrant survival reflected results from juvenile mark/recapture experiments by Sims and Ossiander (1981) conducted at Snake and Columbia River dams during the 1970s. As indicated earlier in this paper, 48-hour post-marking delayed mortalities were high during this period due to the problems attendant at collection dams and the methods of fish handling. As a result, many smolts marked and released at an upstream dam did not arrive at downstream sites since large numbers obviously died after release simply due to the physical traumas suffered during collection and marking. During the mark/recapture studies (Raymond 1979; Sims and Ossiander 1981) to estimate flow/travel time and flow/survival, release numbers were not adjusted to reflect even the short-term 48-hour delayed mortalities, much less those that probably occurred over a longer period. Further, all smolts released from upstream sites and not recovered at downstream sites were assumed to have died as a result of passage through the hydropower complex, with survivals varying due to changes in river discharge. These analyses did not consider smolt condition and undoubtedly resulted in artificially high in-river mortality estimates that were attributed entirely to changes in flow and dam passage conditions. Passage conditions at dams and fish-handling techniques have improved substantially since the 1970s. Thus, models based upon conditions existing during the 1970s probably underestimate in-river survival of marked juvenile fish used in recent transportation studies.

Another problem with the model for estimating in-river survival was the assumption that per project mortality was the same for all projects. A preliminary review of the data collected during the 1970s indicated that fish mortality was much higher at the first dams encountered by marked smolts. This was particularly true for fish arriving at Lower Granite and Little Goose Dams because debris from the Snake River accumulated at these projects and negatively influenced fish condition.

Use of the measured T/C estimate without considering the statistical error bound may also lead to erroneous conclusions. All measured T/Cs have very broad 95% confidence intervals. A seemingly small difference in the T/C estimate could make a large difference in the inferences drawn from the model.

The argument that spring/summer chinook salmon populations have not rebounded because smolt transportation does not work is inconsistent with results for steelhead. The T/Cs measured for steelhead have been similar to those measured for spring/summer chinook salmon. Both species face the same conditions during passage through the hydropower system. Steelhead populations have recovered substantially under the transportation program. Although hatchery fish dominate the juvenile out-migrations of both stocks, the spring/summer chinook salmon hatchery component has a very low survival compared to the steelhead component.

In summary, the majority of evidence indicates that transportation is beneficial to spring/summer chinook salmon. The strong recovery of wild populations during the mid-1980s and recent study results indicate that transportation of this stock should be maximized. Smolt transportation, however, may not dramatically increase adult returns of the ever-increasing population of hatchery smolts that appear to have inherent poor survival.

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Impact of Bacterial Kidney Disease on Chinook Salmon Smolts during Migration, Collection, and Transportation

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The transportation of salmonid smolts downriver past Snake River and Columbia River hydroelectric dams has shown benefits for fall chinook salmon *Oncorhynchus tshawytscha* and steelhead *O. mykiss*; the adult returns of transported fish to the dams have been consistently higher than those for nontransported fish (Park 1985; Raymond 1988). Nevertheless, adult returns of the spring race of chinook salmon have remained low regardless of whether or not they were transported as juveniles (Park 1985; Raymond 1988). There is concern that hatchery-produced spring chinook salmon smolts may be of poor quality and consequently unable to survive the stresses of migration and entry into the ocean. In particular, there is concern that bacterial kidney disease (BKD) caused by *Renibacterium salmoninarum* may be a significant factor in the poor survival of spring chinook salmon smolts (Matthews et al. 1985; Park 1985; Raymond 1988). Until recently, however, there were few quantitative data available on the prevalence and severity of BKD in salmonids in the Snake and Columbia Rivers.

In 1988, the U.S. Fish and Wildlife Service (USFWS) began a study, sponsored by the U.S. Army Corps of Engineers, to evaluate the impact of BKD on transported and nontransported spring and summer chinook salmon smolts in the Snake and Columbia River basins. Two of the major objectives of this study were to monitor the prevalence and levels of *R. salmoninarum* infections in spring and summer chinook salmon smolts arriving at the juvenile fish collection facilities at selected hydroelectric dams, and to determine the potential for the horizontal transmission of *R. salmoninarum* among juvenile salmonids during collection or transportation.

To meet the first objective, the prevalence and severity of *R. salmoninarum* infections were determined in samples of spring/summer chinook salmon out-migrants collected at selected hydroelectric dams on the Columbia and Snake rivers. The second objective included two principal tasks: (1) to determine whether detectable numbers of viable *R. salmoninarum* cells were present in the water of the rivers, the fish collection raceways, and the fish transportation barges; and (2) to determine whether exposing healthy salmonids to waterborne *R. salmoninarum*, or to salmonids infected with the bacterium, could result in the successful horizontal transmission of the infection. This report emphasizes the results obtained from studies at Snake River locations, except for cases where data are available only from studies at Columbia River locations or from laboratory studies.

Methods

Monitoring R. salmoninarum Infections in Spring/Summer Chinook Salmon Smolts

In the Snake River, random samples of spring/summer chinook salmon smolts were taken from the juvenile fish collection facility at Lower Granite Dam over the duration of the out-migration in 1988, 1989, 1990, and 1991. A daily subsample of 20-25 fish was taken on most days; the daily subsample was increased to 50 fish during the approximately 10 d of peak smolt movement. The total number of fish tested ranged from 1,679 to 2,158 (Table 1). Tissues from the fish were processed and tested for the presence of *R. salmoninarum* infections by a quantitative serological test, the enzyme-linked immunosorbent assay (ELISA; Pascho and Mulcahy 1987) according to the procedures described by Pascho and Elliott (1989). The positive-negative threshold values for the fish tissues tested by the ELISA were calculated by the method of Pascho et al. (1987). Each fish testing positive by the ELISA was categorized as having a low, medium, or high *R. salmoninarum* infection level as described by Pascho et al. (1991). Briefly, the *R. salmoninarum*-positive samples with ELISA values between the positive-negative cutoff optical density (OD)

Table 1. Results of ELISA testing of spring/summer chinook salmon smolts collected at Lower Granite Dam over the duration of the out-migration from 1988 through 1991. The *Renibacterium salmoninarum* infection categories are described in the text.

Year	Total number of fish sampled	Number of fish in each infection category (percent)			
		Negative	Low	Medium	High
1988	1,999	284 (14%)	1,166 (58%)	398 (20%)	151 (8%)
1989	2,158	54 (3%)	1,000 (46%)	643 (30%)	461 (21%)
1990	1,679	128 (8%)	1,163 (69%)	325 (19%)	63 (4%)
1991	1,994	81 (4%)	1,459 (73%)	361 (18%)	93 (5%)

value and 0.199 were considered to have low R. salmoninarum infection levels, those with OD values of 0.200 to 0.999 were considered to have medium infection levels, and those with OD values ≥1.000 were considered to have high infection levels.

Water Samples

Water samples were taken from selected sites in the Snake and Columbia Rivers in 1988, 1989, and 1990. Most of the samples were taken from McNary Dam on the Columbia River, but some water was also sampled from Lower Granite Dam on the Snake River. Most samples were taken near the peak of the spring/summer chinook salmon out-migration (April and May), but some were taken during February or March, before the out-migration, or in July, during the fall chinook salmon out-migration at McNary Dam. All samples were processed and analyzed for the presence of *R. salmoninarum* cells by the membrane filtration-fluorescent antibody technique (MF-FAT; Elliott and Barila 1987) according to the methods described by Elliott and Pascho (1991). In addition, a portion of the samples from McNary Dam were cultured on bacteriological media for the attempted isolation of viable *R. salmoninarum* as described by Elliott and Pascho (1991).

Live-Box Tests

To investigate the potential for the transmission of *R. salmoninarum* infections among juvenile salmonids during migration, collection, and transportation, live-boxing experiments were performed at various locations at McNary Dam, and on barges traveling between McNary Dam and Bonneville Dam, in 1989 and 1990. Live-boxes containing subyearling brook trout *Salvelinus fontinalis* were placed in the Columbia River at the upstream face of the dam, in fish collection raceways, and on fish transportation barges, according to the procedures of Elliott and Pascho (1991; 1992). Fish were held in the live-boxes for up to 24 h, then transported to the USFWS Columbia River Field Station at Cook, Washington, and held for 14 weeks in tanks of clean running water. At the end of the holding period, fish that died during the experiments, as well as the survivors, were processed and tested by the ELISA.

Laboratory Challenge Experiments

Laboratory challenges were conducted at the National Fisheries Research Center-Seattle to obtain more information about the numbers of *R. salmoninarum* cells in the water, or the infection levels in fish, required for successful transmission of the bacterium to healthy fish. For one experiment (a cohabitation challenge), groups of subyearling spring chinook salmon (obtained as eggs from parent fish at Dworshak National Fish Hatchery with very low *R. salmoninarum* infection levels) were injected with an isolate of *R. salmoninarum* that originated from spring chinook salmon at that hatchery. Three different concentrations (2×10^4, 1×10^6, and 2×10^8 cells/fish) of *R. salmoninarum* were used; two groups of 40 fish each were injected with a given concentration. The goal was to create groups of fish with a range of *R. salmoninarum* infection levels similar to the range seen in spring/summer chinook salmon smolts sampled during our monitoring at the collection facilities at the dams. Groups of uninjected fish served as controls. The fish were held in tanks of clean running water for two weeks to allow infection to develop. Groups of 60 subyearling brook trout each were then placed in live-boxes and lowered into the tanks. Loading densities were maintained at about 60 g of fish/L of water, similar to the maximum loading densities used for salmonids during collection or transportation in the Snake River. After 48 h (the maximum time that fish would be held in raceways or on a barge during collection and transportation), the chinook salmon were killed and the *R. salmoninarum* infection levels in their kidney and spleen tissues were measured by the ELISA according to standard procedures (Pascho and Elliott 1989; Pascho et al. 1991). The brook trout were maintained in clean running water at a loading density ≤6 g/L. A subsample of 20 fish from each group was sacrificed six weeks after challenge and examined for *R. salmoninarum* infection by the ELISA. The remaining fish were held for 14 weeks, and then sacrificed and tested by the ELISA.

For the second experiment, brook trout were exposed to three different concentrations of *R. salmoninarum* (1.3×10^1, 1.3×10^3, and 1.3×10^5 cells/mL) in flowing water for 48 h. These bacterial concentrations were within the range detected by the MF-FAT or culture in water samples from the Columbia River or Snake River sites described above. The bacterial preparations were metered into the water supply for each tank by use of peristaltic pumps. Two groups of 60 fish each were exposed to a given concentration of bacteria; control groups were exposed to bacterial culture diluent (peptone-saline) only. After the challenge, the fish were placed in clean running water. Tank loading densities during the challenge and holding periods were the same as for the cohabitation experiment. After six weeks, 20 fish from each group were sacrificed and tested for *R. salmoninarum* infections as described above; we planned to hold the remaining fish for a total of 14 weeks.

Results and Discussion

Monitoring of R. salmoninarum Infections in Spring/Summer Chinook Salmon Smolts

The prevalence of *R. salmoninarum* infection was high (>85%) in spring/summer chinook salmon smolts at Lower Granite Dam during all four years of sampling (Table 1), ranging from 86% in 1988 to 97% in 1989. Although the prevalence of infection was high, during most sample years the majority of the infected fish had low infection levels (Table 1). There were year-to-year variations in the severity of infection, however. The 1989 sample was most notable, because 51% of all of the fish tested that year showed medium to high *R. salmoninarum* infection levels.

The overall severity of *R. salmoninarum* infection also showed changes as the out-migration progressed during a given sample year. During each year, the highest proportions of severely infected fish were found in the samples taken from the middle to the end of the out-migration. During the peak of the out-migration, when the highest numbers of spring/summer chinook salmon smolts were being collected for transportation or bypass, the overall infection severity in the fish was relatively low.

Water Samples

Water sample testing by the MF-FAT indicated that *R. salmoninarum* was present in all locations sampled at both Lower Granite Dam and McNary Dam. At a given sample time the bacteria were present in roughly equivalent numbers in the river water samples taken at Lower Granite and McNary Dams (Table 2) and in the samples taken from the fish collection raceways and transport barges at McNary Dam (Table 3). Bacterial counts tended to be highest in samples taken near the peak of the spring/summer chinook salmon out-migration. Although the *R. salmoninarum* counts by the MF-FAT in 1989 and 1990 averaged less than 2,000 bacteria/L, limited sampling at McNary Dam near the peak of the spring/summer chinook salmon out-migration in 1988 (a low-water-flow year) showed counts averaging more than 39,000 *R. salmoninarum* cells/L (Tables 2 and 3). The 1988 samples were tested by an MF-FAT that used polyclonal antiserum prepared against *R. salmoninarum*, whereas the 1989 and 1990 results shown were obtained by a procedure that used monoclonal antibodies prepared against this bacterium. A comparative study of the two MF-FATs in 1989 (Elliott and Pascho 1991) showed comparable results in most cases, however.

One problem with the MF-FAT is that it cannot determine the viability of the bacteria detected. The culture of *R. salmoninarum* from environmental samples is difficult because this fastidious bacterium is easily overgrown by other bacteria and fungi present in samples. Nevertheless, the presence of viable *R. salmoninarum* in the water of barges loading fish at McNary Dam was confirmed by culture in both 1989 and 1990 (Table 3); the 1989 culture results suggested that *R. salmoninarum* concentrations as high as 1.4×10^6 cells/mL were present near the peak of the spring/summer chinook salmon out-migration.

Live-Box Tests

The live-box studies conducted in 1989 indicated that *R. salmoninarum* was transmitted to some brook trout that had been live-boxed in the river and in fish collection raceways at McNary Dam, as well as to some of

Table 2. Results of MF-FAT testing of river water samples from Lower Granite Dam and McNary Dam in 1989 and 1990 for the detection of *Renibacterium salmoninarum*. The samples were taken at the upstream face of each dam.

	Mean number of *R. salmoninarum* cells/L of water (±SD)		
Location and year	February-March	April-May	July
Lower Granite Dam			
1989	345 (±169)	1,486 (±662)	...
1990	209 (±295)	313 (±142)	...
McNary Dam[a]			
1989	105 (±115)	1,183 (±517)	608 (±222)
1990	105 (±149)	1,559 (±845)	1,383 (±1,665)

[a] Mean *R. salmoninarum* concentrations of 29,000 (±14,014) cells/L were detected by the MF-FAT in water samples taken from the river in May 1988.

Table 3. **Results of MF-FAT testing of water samples from fish collection raceways and fish transport barge tanks at McNary Dam in 1989 and 1990 for the detection of *Renibacterium salmoninarum*.**

	Mean number of *R. salmoninarum* cells/L of water (±SD)	
Location and year	May	July
Raceway[a]		
1989	1,403 (±689)	677 (±701)
1990	576 (±465)	219 (±310)
Barge[b]		
1989	1,552 (±443)[c]	473 (±474)
1990	682 (±618)[d]	516 (±139)

[a] Mean *R. salmoninarum* concentrations of 39,667 (±15,680) cells/L were detected by the MF-FAT in water samples taken from raceways in May 1988.

[b] Mean *R. salmoninarum* concentrations of 37,000 (±9,839) cells/L were detected by the MF-FAT in water samples taken from barge tanks in May 1988.

[c] *R. salmoninarum* was cultured from a barge water sample on May 11, 1989; the culture results indicated that the concentration of viable bacteria in this water sample was 1,400,000,000 cells/L.

[d] *R. salmoninarum* was cultured from a barge water sample on May 10, 1990; the culture results indicated that the concentration of viable bacteria in this water sample was 10,000 cells/L.

Table 4. Results of liveboxing tests conducted with brook trout at McNary Dam in 1989. Groups of about 110 fish each were held in liveboxes in the river (at the upstream face of the dam) and in the raceways for about 24 h, and in the barges for about 16 h. After the liveboxing period, the fish were transported by truck to the Columbia River Field Station at Cook, Washington, and held for about 100 days. The results shown are the percent of fish testing positive by the ELISA; fish tested included those that died during the holding period, and fish that survived to the termination of the experiment. Liveboxing experiments were repeated during 1990, but none of the liveboxed fish tested by the ELISA at the end of the holding period were positive for *Renibacterium salmoninarum* infections.

	Percent of fish positive for *R. salmoninarum*	
Location	May[a]	July[b]
River	0	2
Raceway	9	3
Barge[c]	0	2

[a] 118 fish tested per group

[b] 59-60 fish tested per group

[c] Fish were placed on the barge at McNary Dam and unloaded at Bonneville Dam.

the trout that had been live-boxed in barges that were transporting fish from McNary Dam for release below Bonneville Dam (Table 4). Infected brook trout were detected among fish that had been live-boxed near the peak of the spring/summer chinook salmon out-migration in May, and in groups that had been live-boxed in July, during the fall chinook salmon out-migration. The prevalence of *R. salmoninarum* infection in the groups of live-boxed trout was relatively low ($\leq 9\%$). It is not known whether a live-boxing period longer than 24 h (e.g., up to the 48 h maximum that fish would probably be held in raceways or barges) would have resulted in an increase in the proportions of fish that were infected.

In 1990, no infected fish were detected in any of the groups of live-boxed brook trout. The reasons for the differences between the 1989 and 1990 results are not known, although it is possible that the fish in the 1989 tests were exposed to migrating salmonids with higher *R. salmoninarum* infection levels than those in the 1990 tests. The *R. salmoninarum* infection levels in spring/summer chinook salmon and steelhead collected at McNary Dam in 1989 were higher than those in the fish of these species collected in 1990 (Elliott and Pascho 1992), but no fall chinook salmon subyearlings were tested for *R. salmoninarum* during either year.

Laboratory Challenge Experiments

The results of the cohabitation experiment indicated that brook trout could become infected with *R. salmoninarum* by being held for 48 h in live-boxes in a tank containing spring chinook salmon infected with various levels of *R. salmoninarum* (Table 5). The infection levels created in the chinook salmon by injection were, as planned, within the range of levels measured in smolts collected at the hydroelectric dams during the spring/summer chinook salmon out-migration. The prevalence of infection was highest in the brook trout that were exposed to the most severely infected chinook salmon.

Cultures of water samples taken from the tanks with the most severely infected chinook salmon revealed that the numbers of viable *R. salmoninarum* in the water remained at about 6.0×10^2 cells/mL for the duration of the cohabitation exposure. This was higher than the highest counts (4.0×10^1 cells/mL) obtained by the MF-FAT in our 1988-1990 survey of the presence and numbers of *R. salmoninarum* cells in water samples from various locations in the Columbia and Snake River basins (Tables 2 and 3), but lower than the highest count of viable bacteria (1.4×10^6 cells/mL) obtained by culture from a barge water sample during this survey. No *R. salmoninarum* was cultured from the challenge tanks containing the less severely infected chinook salmon; bacterial counts will be obtained by MF-FAT analysis of water samples.

The preliminary results of the 48 h waterborne challenge experiment further demonstrated that brook trout could be infected with *R. salmoninarum* in flowing water containing the bacterium but no infected fish (Table 6). At six weeks postchallenge, *R. salmoninarum* infections were detected in some fish exposed to concentrations as low as 1.3×10^3 *R. salmoninarum* cells/mL, and in all of the tested fish in groups that had been exposed to the highest bacterial concentration (1.3×10^5 cells/mL). The holding period for this experiment was scheduled to continue for an additional eight weeks. The preliminary results suggested that fish migrating or residing in the river could become infected with *R. salmoninarum* originating from remote sources (e.g. from hatchery outfalls or streams containing infected fish), provided that the bacteria could survive for an extended period of time in the absence of fish. One experiment has shown that *R. salmoninarum* can survive for at least 21 days in sediment and fecal material in tanks containing no fish (Austin and Rayment 1985).

Further waterborne challenges and cohabitation experiments (with juvenile spring chinook salmon only) are in progress. Half of the fish in each test or control group of chinook salmon will be transported to the USFWS Marrowstone Field Station at Nordland, Washington, for extended seawater holding; the remaining fish will be held in fresh water.

Summary

1. A 4-year survey (1988-1991) showed the prevalence of *Renibacterium salmoninarum* to be >85% in spring/summer chinook salmon smolts arriving at Lower Granite Dam.

Table 5. Results of a cohabitation experiment in which brook trout were liveboxed for 48 h in tanks containing juvenile spring chinook salmon that had been injected 2 weeks previously with various concentrations of *Renibacterium salmoninarum*. The control fish were exposed to chinook salmon that had been injected with sterile saline. Test and control groups were run in duplicate; the combined results for both tanks of a given group are shown.

Group	Injected chinook salmon Mean ELISA OD (±SD)[a]	Liveboxed brook trout Percent positive for *R. salmoninarum* infection 6 weeks post-challenge[b]	 14 weeks post-challenge[c]
Control	0.071 (±0.006)	0	0
Low	0.274 (±0.326)	0	1
Medium	1.333 (±0.534)	0	1
High	2.497 (±0.671)	5	10

[a] Chinook salmon (80 per group) were tested immediately after the completion of the 48-h cohabitation challenge.

[b] 20 fish per group were tested by the ELISA.

[c] 100 fish per group were tested by the ELISA.

Table 6. Preliminary results of a waterborne challenge experiment in which brook trout were exposed to various concentrations of *Renibacterium salmoninarum* for 48 h in flowing water. Test and control groups were run in duplicate; the combined results for both tanks of a given group are shown.

Group	Concentration of *R. salmoninarum* in challenge tanks (bacteria/mL)	Percent of brook trout positive for *R. salmoninarum* infection 6 weeks post-challenge[a]
Control	0	0
Low	1.3×10^1	0
Medium	1.3×10^3	20
High	1.3×10^5	100

[a] 20 fish per group were tested by the ELISA.

2. The majority of the fish testing positive for *R. salmoninarum* infections during all but one sample year (1989) had low infection levels.

3. The average severity of *R. salmoninarum* infections in the spring/summer chinook salmon smolts showed an increase toward the middle to end of the out-migration during each survey year, but the average severity of infection was low when the greatest numbers of fish were collected for transportation or bypass.

4. Research results suggest that conditions conducive to the horizontal transmission of *R. salmoninarum* are present in at least some areas of the Snake and Columbia River basins: a high proportion of the spring/summer chinook salmon out-migrants are infected with the bacterium, and *R. salmoninarum* cells have been identified in the water at several locations.

5. The results of field live-boxing studies and laboratory challenge experiments suggested that healthy salmonids could become infected with *R. salmoninarum* during migration, collection, and transportation in water containing viable *R. salmoninarum* cells, or infected fish shedding these bacteria.

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To Be or Not To Be a Healthy Smolt

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What makes a healthy smolt? There is no one part the salmon's early life cycle that is the key to perfection. It is important to understand and practice good fish culture at each stage of growth to attempt to produce a quality smolt. Hatchery smolts are not perfect, nor are they floating debris on the way to the ocean. At all stages of growth we are searching for methods to reduce stress on the fish. We are seeing a better-quality product now than we did ten to twenty years ago. To be successful in producing quality smolts, we must work together as a team. In producing hatchery spring chinook, each year the question is the same: Will the smolts be quality smolts?

The early years of raising hatchery smolt consisted of feeding drugged feed at low levels to hatchery fish, saving all pond mortalities to look for bacterial kidney disease, and picking up mortalities by the garbage-can-full. At the present we are still looking for the one main answer to a simple question: How can we increase our smolt survival to give us large returns of quality adults? I am confident there is not a single or a simple answer.

Yes, we have made progress, and that progress has been masked by many other variables. The progress I am talking about is in the hatchery system, since I do not have the expertise or the or the statistics to say much about what happens once the fish are released. We have seen better-quality fish and more survivors within the hatchery system, and in most cases we see a product we can be proud of. No, we have not arrived at perfection and probably never will, but we are making progress. Our goals are your goals: Not to see fish die in the hatchery or to barely make it to the dam. We want to produce a quality adult that you and our children can be proud of.

What makes a healthy smolt? There is no single answer, and although many factors contribute to survival and quality, common sense is the main factor. We must question, study, and understand each stage in the life cycle of a salmon to even try to culture the quality we want and need. Ask any husbandman what is important to his animal, and he will list the same factors as another: Stress reduction, environment, disease control, nutrition, and other common-sense factors.

The key is balance. Balance is important to any aspect of our lives. A balance is seldom stable, but it does not tip drastically from one point to the other. We are the pivot point on the basis of how we culture, manage, protect, and plan for our product. It is difficult to separate what is biological from what is political. It is up to us to ask questions, demand accurate data, and to listen to more than one source as we search for the correct answers.

As I have stated, hatchery fish are not perfect, nor are they floating debris on the way to the ocean. We have incorporated better spawning techniques, the use of antibiotic injections, the disinfecting of eggs, and reduced stocking densities; and we have demanded better feed. We continue to search for more protection after release and for more controls on the high sea fisheries. We have better controls on the returning adults and better care for our adults when they return to the hatchery. In all phases we are searching for methods to reduce any stress on the fish. We need to find a means of marking the fish that will reduce stress and increase their chances for survival. I personally have seen and continue to see a better-quality product than was produced 10 to 20 years ago.

New techniques for adult handling, antibiotic injections for adults, segregating eggs on the basis of disease incidence in parent stock, more sensitive equipment and testing, and better fish culture are being used. We have seen bacterial kidney disease losses in our ponds go from 30-50% to 10-15%, and fewer signs of disease in the returning adults. There is much more research being done. Again, I do not want to give the impression that we have arrived, but we have hope, and knowledge on which we can progress.

Fish Health and Disease Problems

Seventy-five percent of fish health problems are due to stress, density, feed, handling, marking, early drop out, and incubation problems, including weak eggs and deformities. Twenty-five percent are due to BKD, smoltification, osmoregulation, marking lesions, IHN, EIBS, eye-up problems, environment, nitrogen gas, and transfer. The final twenty-five percent are due to coagulated yolk, parasites, and gill bacteria.

To be successful in producing quality smolts we must work together as a team. As a team we are honest and sincere about our goals, and we share our knowledge without personal prejudice or biases.

Fish Health Monitoring: Beyond the Raceway

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Introduction

The mass transport of Columbia River basin juvenile salmonids implemented during the late 1970s and early 1980s, and the development of hatchery production programs in northeastern Oregon throughout the 1980s, raised concerns within the Fish Pathology section of the Oregon Department of Fish and Wildlife (ODFW). Initially, these concerns focused on the potential impact that infectious hematopoietic necrosis (IHN) might have on both hatchery and natural salmonid populations as they were collected for transport (Groberg 1983). It was also perceived that bacterial kidney disease (BKD), because of its chronic and persistent nature, could reduce survival during and after out-migration to the marine environment. Studies have shown that these concerns were justified relative to the causative agent of BKD, *Renibacterium salmoninarum* (Banner et al. 1986; Sanders et al. 1992). Smolt out-migration, seawater adaptation, and survival to spawning adult were all shown to be lifecycle phases adversely affected by *R. salmoninarum* infection. Bartholomew et al. (accepted for publication) examined the possible role that the intestinal myxosporean parasite *Ceratomyxa shasta* might also have on out-migration success and seawater adaptation. Those studies indicated that ceratomyxosis could be a factor affecting survival under certain conditions. The potential for numerous other pathogens and parasites of Columbia River basin salmonids to reduce survival during life stages beyond their hatchery tenure as juveniles has received minimal evaluation.

Data documenting passage indices of only 8-30% at Lower Granite Dam in recent years (Messmer et al. 1989; Messmer et al., in press) indicate that a large portion of hatchery chinook liberated at northeastern Oregon sites subsequently fail to appear at Snake River dam collection facilities. This information exacerbated previous concerns about disease and raised immediate questions as to whether disease might be a component of this loss. Augmented Fish Health Monitoring, funded by the Bonneville Power Administration (BPA), of fish in the hatchery environment over the past five years does not support the notion that disease occurring in fish at liberation could account for this disturbing lack of out-migrant smolts at Snake River dams. Conversely, there are sparse data documenting infectious and parasitic agents acquired after fish depart raceways and natal streams that could affect the immediate and long-term survival of both hatchery and natural fish. Further, little is known of the implications for disease as the myriad of hatchery-originated and natural populations begin to interact during migration, and during cohabitation imposed by collection and transport.

This paper is a collection of observations the ODFW has assimilated from very limited diagnostic work on out-migrant salmonids from the Snake River. These case histories can only serve as examples of how the host-pathogen-environment interaction can produce disparate outcomes. From this information, an assessment of the need for comprehensive fish health evaluations of smolts at Snake River collection facilities can be made.

Methods

Case History One: Chinook, 1984

In April of 1984, ODFW fish biologists collected 30 juvenile chinook salmon *Oncorhynchus tshawytscha* that they observed to be in a moribund condition during trapping operations at Little Goose Dam on the Snake River. These fish were transported on ice to ODFW fish pathologists at Oregon State University. On the basis of size and fin clips, all fish were judged to be of hatchery origin; this, however, was not confirmed.

Diagnostic assays for *R. salmoninarum* and culturable viruses were performed on individual samples from each fish. *R. salmoninarum* was detected by Gram stain and the direct fluorescent antibody test (DFAT) on smears made from kidney tissue. Viral assays were performed on samples of pyloric ceaca/kidney/spleen (PKS) according to methods described in the Fish Health Blue Book (Amos 1985).

Case History Two: Rainbow 1986

Between August 20 and September 17 of 1986, nine subyearling rainbow trout *O. mykiss* were submitted to ODFW fish pathologists for viral examinations. Fish in this population were undergoing a chronic mortality while being held in a quarantine facility at Round Butte Hatchery on the Deschutes River in central Oregon, and no etiological agent had been isolated. These animals were sentinel fish for a *C. shasta* investigation, and had previously been live-boxed for 14 days in the Clearwater River at the returning adult attraction flume for Dworshak National Fish Hatchery. The flume water was a combination of Clearwater River water, adult holding pond effluent, and juvenile rearing pond effluent. Two weeks prior to live-boxing the rainbow, the adult holding pond had held mature summer steelhead *O. mykiss* adults known to be carriers of IHN virus. At the time of live-boxing, the adult pond held early returning spring chinook salmon adults. Also, an epizootic of IHN in juvenile summer steelhead in rearing ponds at Dworshak began on June 30, 1986, one day before the rainbow began their 14-day live-box exposure (Joe Lientz, personal communication). However, hatchery personnel were unaware of the epizootic at the time of live-boxing. Individual gill, brain, and kidney/spleen samples were assayed by plaque titration methods (Burke and Mulcahy 1980).

Case History Three: Steelhead, 1988

In June of 1988, ODFW fish biologists collected 15 juvenile steelhead that they observed to be in a moribund condition during trapping operations at Little Goose Dam. These fish were frozen and delivered to the ODFW Fish Pathology Laboratory in La Grande, Oregon. On the basis of adipose fin clips, the fish were judged to be a combination of hatchery and natural fish. Viral examinations of two PKS sample pools (seven fish per pool) were done as described above for chinook. Lower intestinal tract scrapings were examined for *C. shasta* by light microscopy of wet mounts.

Case History Four: Chinook and Steelhead, 1989

During May of 1989, ODFW fish biologists and fish pathologists conducted comprehensive on-site fish health examinations on nine chinook and thirteen steelhead at Little Goose Dam. These juvenile out-migrants were moribund or dead, and were examined under protocols similar to those followed under the BPA-funded Augmented Fish Health Monitoring project cited above. Body surface and intestinal tract scrapings and gill wet mounts were examined by light microscopy for parasites and for general condition. Blood smears were made from moribund chinook and examined for erythrocytic inclusion body syndrome (EIBS) by light microscopy after pinacyanol chloride staining. Bacteriological media were inoculated with smears from gill and kidney tissue. Kidney smears were made on microscope slides and examined for *R. salmoninarum* by the DFAT. Viral assays were not done. These fish were thought to be of a combined hatchery and natural origin.

Results

Case History One: Chinook, 1984

Most fish (19/30) showed some clinical signs consistent with BKD pathogenesis: darkened body color, exophthalmic and opaque eyes, abdominal distention, and petechial hemorrhages on the body surface. Gross kidney lesions were also observed in most of the 19 fish that were positive for *R. salmoninarum*, while 11 of the fish were negative both by Gram stain and the DFAT. The prevalence of *R. salmoninarum* was therefore 63%. No viral agents were detected by cell culture assays.

Case History Two: Rainbow, 1986

Table 1 shows the recovery data of infectious hematopoietic necrosis virus (IHNV) from subyearling rainbow trout experiencing a chronic mortality after live-box exposure in the Clearwater River. Of nine fish sampled, none were found positive (0%) for the virus by kidney/spleen tissues, five were found positive (56%) by gill samples, and seven were found positive (78%) by brain samples. Virus titers, measured by plaque-forming units per gram of tissue (pfu/g), were higher in every instance from brain tissue. In five of the seven fish that were IHNV positive, virus titers were 1-3 logarithmic units greater in the brain than in the corresponding gill sample. Plaque reduction profiles of these isolants with two IHNV-neutralizing reagents revealed that they were similar to the profile obtained with a Dworshak steelhead isolant, and different from the profile obtained with a Round Butte steelhead isolant.

Case History Three: Steelhead, 1988

Thirteen of fifteen fish had severe lower intestinal tract hemorrhaging typical of ceratomyxosis, and the remaining two showed moderate hemorrhaging. Spores of *C. shasta* were observed at high levels in twelve of fifteen (80%) fish, at low levels in two of fifteen (13%), and were not observed in one (7%) fish. No viral agents were detected by cell culture assays.

Case History Four: Chinook and Steelhead, 1989

The results of these comprehensive examinations are summarized in Table 2. External parasites were not observed on three moribund fish examined. Neither *C. shasta* nor *R. salmoninarum* were detected in any of 22 fish. One of three chinook had inclusions typical of EIBS, and three of three moribund fish had typical gill disease bacteria. Only dead fish harbored systemic aeromonad/pseudomonad bacteria (33%).

Discussion

Infectious disease results from complex interactions between susceptible hosts, their pathogens, and the environment. Environmental influences are especially significant for poikilothermic vertebrates in an aquatic habitat. The transmission of infectious agents is facilitated in this medium, and the physiology of both the host and pathogen is directly influenced by environmental parameters, especially temperature. Many environmental parameters are continually changing for Columbia River basin salmonids as they migrate seaward. The potential for a variety of disease conditions is therefore diverse, and is subject to temporal and geographical influences. The case histories reported here are intended to support these concepts (Table 3).

In 1984, BKD was of such severity in out-migrating chinook that ODFW fish biologists observed an unusually high number of moribund fish during trapping operations. Pathologic signs and the detection of *R. salmoninarum* at levels consistent with the disease allowed severe BKD to be confirmed in 63% of those fish examined. Subclinical infections were probably present in many fish appearing to be normal; these infections later produced clinical disease and mortality. An effort to alert fisheries professionals to the circumstances of this case was made in the Fish Health Newsletter (Groberg 1984).

While the 1986 episode of IHN in rainbow live-boxed below a hatchery did not occur in migrating fish, it clearly demonstrates that possibility. The fundamental concept of infection suggests that fish moving past a hatchery with an ongoing epizootic by an infectious agent are vulnerable. This is one of many reasons that outbreaks of infectious diseases in hatcheries need to be prevented or controlled as early as possible, preferably through the use of legal and effective vaccines or therapeutants. The delayed onset and atypical nature of the IHNV infection in neural tissue in this case would have made a diagnosis in out-migrating fish unlikely.

Table 1. Infectious hematopoietic necrosis virus (IHNV) titers in kidney-spleen (KS), gill and brain tissues from subyearling rainbow trout (*Oncorhynchus mykiss*) experiencing a chronic mortality.

Fish Number	Date of Mortality	IHNV Titer (pfu/g)[1]		
		KS	Gill	Brain
1	20 Aug 86	0	0	5.4×10^3
2	20 Aug 86	0	0	0
3	22 Aug 86	0	0	2.0×10^2
4	22 Aug 86	0	0	0
5	24 Aug 86	0	1.2×10^3	2.8×10^3
6	29 Aug 86	0	6.0×10^2	6.0×10^4
7	31 Aug 86	0	3.0×10^3	1.5×10^4
8	1 Sep 86	0	1.6×10^3	$>1.0 \times 10^5$
9	17 Sep 86	0	6.0×10^3	$>1.0 \times 10^5$

[1] Titer in plaque forming units per gram of tissue (pfu/g). Minimum level of virus detection is 1.0×10^2 pfu/g. Therefore, in samples with a titer of 0, virus could have been present below the minimum level of detection.

Table 2. Results of comprehensive examinations for fish pathogens in moribund and dead chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*) at Little Goose Dam in May of 1989.

		Proportion Positive					
		External		Bacteria			
Clinical State	Species	Parasites	EIBS	Gills	Systemic	*Cs*	*Rs*
Moribund	St	0/1	ND	1/1	0/1	0/1	0/1
Moribund	Ch	0/2	1/3	2/2	0/3	0/3	0/3
Dead	St	ND	ND	ND	3/12	0/12	0/12
Dead	Ch	ND	ND	ND	3/6	0/6	0/6

Abbreviations:

St = steelhead, Ch = chinook salmon, EIBS = erythroctyic inclusion body syndrome, *Cs* = *Ceratomyxa shasta*, *Rs* = *Renibacterium salmoninarum*, ND = not done

Table 3. Identity and prevalence of predominant fish pathogens detected in juvenile salmonids from the Snake River basin in four clinical case histories.

Date of Case History	Fish Species	Pathogen Detected	Prevalence of Pathogen Proportion	Percent
Apr 1984	Ch	*Rs*	19/30	63
Sep 1986	Rb	IHNV	7/9	78
Jun 1988	St	*Cs*	14/15	93
May 1989	St & Ch	GDB	3/3	100

Abbreviations:

Fish Species: Ch = chinook salmon (*Oncorhynchus tshawytscha*), Rb = rainbow trout (*O. mykiss*), St = steelhead (*O. mykiss*)

Pathogen Detected: *Rs* = *Renibacterium salmoninarum*, IHNV = Infectious hematopoietic necrosis virus, *Cs* = *Ceratomyxa shasta*, GDB = Gill disease bacteria

In 1988, a high incidence of ceratomyxosis was confirmed in late out-migrating steelhead as evidenced by clinical signs and detection of *C. shasta* spores. Early and prolonged warm spring temperatures, combined with low flows in the Snake River, created environmental conditions favorable for latent infection to progress to fulminating disease. The degree to which this occurs in any given year would depend heavily upon natural conditions beyond the raceway environment.

The attempts at comprehensive fish health examinations in 1989 were very superficial because of the limited sample size (three) of moribund fish. Dying fish present optimal clinical specimens for detecting external parasites, gill bacteria, and primary pathogens. No external parasites were observed on any of the three fish examined, nor were the primary pathogens, *R. salmoninarum* and *C. shasta*, detected that were present in earlier years. The isolation of bacteria typical of those causing gill disease is cause for concern, however. The impairment of gill function during stress from both natural and artificial causes would reduce the endurance of the animal and make it more vulnerable to predation. Osmoregulation and adaptation to the seawater environment might also be difficult for fish so affected. Fish passing through slack water impoundments with large populations of nonsalmonids might be expected to acquire some external parasites and possibly gill bacteria during this portion of their migration. The results from these examinations would tend to support the need for more extensive investigations of this type.

Studies that focus upon specific pathogens or the diseases they cause are essential to assessing their impact on the survival of precious fish stocks. Broad-based information about on-site disease is also needed, however, to supplement studies on specific agents. The recent awareness that large numbers of hatchery chinook salmon released in Snake River tributaries cannot be accounted for at juvenile collection facilities would seem to justify this need. Whether disease is a factor in these losses should be determined. Such an evaluation can be rapidly implemented by targeting clinically ill fish at collection sites. This approach would simply extend the disease monitoring of many of these fish beyond the raceway, as is currently done under the Augmented Fish Health Monitoring project funded by the Bonneville Power Administration. Because of this and other projects, many of the support services and facilities required are currently operational in laboratories within the Snake River basin.

Summary

1. Several agents pathogenic to fish were detected that can affect the survival of out-migrating salmonids from the Columbia River basin. Some of these agents have the potential to affect both short- and long-term survival.

2. There is evidence that some of the infectious agents detected were not present in juvenile hatchery fish when they were liberated. Thus, infections producing a disease state may be acquired during out-migration.

3. Different predominant fish pathogens were diagnosed from clinical specimens in the four case histories documented. Environmental parameters appear to have a major influence on the temporal and geographical occurrence of disease in out-migrants.

4. The transmissibility of some of the infectious agents detected is enhanced under crowded and stressful conditions. Thus, infection between populations could occur during out-migration, collection and transport.

5. There are limited data on pathogens infecting and parasites infesting out-migrating juvenile salmonids from the Snake River basin. To acquire such data would require comprehensive on-site fish health examinations supported by laboratory analyses. Facilities exist within the Snake River basin to support many of these kinds of activities.

6. Little information is available for determining whether disease is a factor in the low passage indices of out-migrating chinook at Lower Granite Dam. The recent listing of certain Snake River chinook stocks as threatened under the Endangered Species Act makes acquiring this knowledge important.

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Fish Health Monitoring of Snake River Chinook Salmon in Washington

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Introduction

Fish health specialists with the Washington Department of Fisheries (WDF) visit a given hatchery every two to four weeks for routine monitoring of hatchery stocks on site. Routine monitoring involves more than checking for specific pathogens or diseases; it also includes the evaluation of overall hatchery practices and the condition of the fish and rearing ponds. Access to wild or natural fish is rare; occasionally we are able to evaluate their condition and to test for the presence of specific fish pathogens.

In addition to undergoing routine monitoring, Snake River salmon stocks in Washington were included in the Bonneville Power Administration (BPA)-funded Augmented Fish Health Monitoring project (fall 1986 through spring 1991). We improved our technical capacities for detecting specific fish pathogens, and also our standardized testing, frequency of testing, and reporting of fish health data. An additional BPA-funded project has provided WDF with a more reliable and quantitative method to use in managing bacterial kidney disease (BKD) that uses the enzyme-linked immunosorbent assay (ELISA).

This presentation is based primarily on my own observations from routine fish health monitoring, and on reports from previous fish health specialists, but it also includes information gained from the Lyons Ferry and Tucannon hatchery staff, Lower Snake River Fish and Wildlife Compensation Plan (LSRCP) biologists, and biologists from the above-mentioned BPA projects. Everyone's assistance and cooperation is greatly appreciated.

Fall Chinook Program

The Lyons Ferry (LF) salmon hatchery's design capacity for fall chinook is 101,800 pounds, programmed as 9.1 million subyearling smolts at 90 fish per pound at release. Eggtakes to date have not met program goals, but poundage has approached capacity due to retaining a portion of the program through to a yearling smolt release. The preliminary results from LSRCP research indicate a higher survival for fall chinook salmon released as yearlings than as subyearlings; therefore, the program has shifted to maximize yearling production. With current eggtakes at one million or less, yearling production is maximized at approximately 800,000 smolts. Brood year (BY) 91 will be entirely a yearling release, BY89 was all subyearlings, and other BYs were a combination of subyearling and yearling release groups.

Fall Chinook Health

Until 1990, the primary fish health problem affecting the fall chinook was bacterial gill disease (BGD). The use of raceway baffles, the addition of limestone, and changes in cleaning schedules, inflows, and exchange time did not reduce the incidence or severity of BGD (Pat Chapman, WDF, personal communication). In the spring of 1990, 1991, and 1992, we discontinued the use of well 4, which was suspect because of high manganese deposits, during the early rearing of the fall chinook. Subsequently, we have not found any sign of BGD. Chinook lateral line syndrome (CHILLS) was detected in the fall of BY83, BY84, BY87, and BY88. CHILLS had not been detected anywhere in the state since the 1960s, when Jim Wood found it at several WDF hatcheries in chinook at 200 to 300 fish per pound (Wood, 1979). Generally, the fish at Lyons Ferry were larger and mortality was less than that observed at hatcheries in the 1960s. CHILLS has recently been detected at a few other WDF hatcheries, and its cause is still unknown. Erythrocytic inclusion body syndrome (EIBS) is an anemia that was associated with each CHILLS case at Lyons Ferry. The cause of EIBS is not established, but viral particles have been observed in red blood cells having the inclusions (Michak et al., in press).

Currently, the most serious fish disease affecting LF fall chinook is BKD, caused by the bacterium *Renibacterium salmoninarum* (Rs). It caused considerable loss in every brood year from 1984 through 1988. BY89 stock was released as subyearlings, before signs of BKD or loss to BKD would normally have been observed. BKD was present in BY90 yearlings, but loss remained very low through rearing. For BY91 we were able to use ELISA results from broodstock females to segregate progeny. The majority of the fall chinook are the progeny of ELISA "low/negative" females: kidney-tissue levels of Rs antigen were so low they can be considered low or negative. We have one pond of approximately 11,000 fall chinook from ELISA "moderate" and "high" females; they will be kept segregated throughout rearing in hopes of preventing the potential horizontal transmission of BKD to "low/negative" progeny.

In addition to the ELISA segregation study, we have studies planned to evaluate the effectiveness of injecting erythromycin into adult females to prevent or reduce the vertical transmission of Rs, and the effectiveness of feeding gallimycin to juveniles to control BKD. Chilled incubation water, first used on BY91 eggs, may also indirectly help us to reduce BKD. First, it delays ponding, which allows us more flexibility in the feeding regime, requiring less "holding back" and reducing the risk of malnutrition and out-of-size fish. Second, resulting pond loadings are easier to keep in line with the recommended density index (DI). We closely monitor pond loadings and make pond splits before reaching a DI of 0.18 lbs/ft^3/in. Not exceeding a DI of 0.17 or 0.18 lbs/ft^3/in for spring chinook reduced the incidence and severity of BKD at the Entiat and Winthrop national fish hatcheries (John Morrison, U.S. Fish and Wildlife Service, personal communication).

Spring Chinook Program

Lyons Ferry's spring chinook program utilizes a rearing pond at the Washington Department of Wildlife's Tucannon hatchery for acclimating fish to river water before their release. The design capacity of the rearing pond is 8800 pounds, programmed as 132,000 yearling smolts at 15 fish per pound at release. Even with reduced feeding regimes, it has been difficult to hold the fish back, and densities at release were above the current recommendation for spring chinook (DI of 0.17 lbs/ft^3/in). We had less than 100,000 smolts for BY89 and BY90, and we had better success in holding them back by feeding to satiation, but less often, e.g., a week's ration was fed out in three or four days. The BY91 fish had the added advantage of chilled incubation water and the delayed ponding that resulted.

Spring Chinook Health

The early rearing of spring chinook at the LF hatchery has not been problem-free. Rs bacteria were detected in preliberation samples of BY87 and BY88 smolts, but significant loss was not attributed to BKD during the routine monitoring of any BY. EIBS has been the most serious fish health problem for the spring chinook smolts. Flexibacter infections, BGD, and columnaris disease have also contributed to loss but in each case were considered to be secondary infections to the EIBS. Inclusions indicative of EIBS were detected one year at LF in spring chinook before transfer to the Tucannon pond, but anemia and loss to EIBS have only occurred after the fish have been held at Tucannon. Inclusions were detected in preliberation samples of three brood years (1986-88), and EIBS was still causing loss at release in BY87 and BY88 spring chinook. Beginning with BY89, we decided to study EIBS, putting about 80% of the fish on a warmer mix (minimum of 40°F) of well and river water until one month before release. The remaining 20% were kept on river water throughout rearing at Tucannon, the standard practice. Before the two study years, river water temperature dropped to freezing and the pond froze over from mid-December through mid-February. Previous studies in Oregon indicated that fish recover from EIBS more rapidly in warmer water (Warren

Groberg, Oregon Department of Fish and Wildlife, personal communication). We expected to detect EIBS in both groups of fish, and to observe a more rapid recovery in fish held on the warmer mixed water supply. Possibly because of reduced densities and generally warmer river water in these years, EIBS was not detected in BY89 and BY90 spring chinook. Keeping the water temperature minimum at 40°F allowed feeding throughout the winter, and should have allowed the fish to maintain a stronger immune response. For these reasons, perhaps the fish overwintered in a healthier condition.

Fish Condition Assessments

Autopsy-based condition assessments (or organosomatic indexes) were included in the Augmented Fish Health Monitoring project and were done on yearling (BY85-88) and subyearling (BY86-90) releases of fall chinook, yearling releases of spring chinook (BY87 and BY88), and wild spring chinook outmigrants (same broods) collected from the downstream migrant trap on the Tucannon River. We have resumed this method of assessment, beginning with the BY90 fish. Spring and fall chinook yearling releases and spring chinook natural outmigrants were sampled in spring 1992. BY90 fish autopsy summaries are included in Appendix 1. Wild and natural outmigrants were also tested for EIBS (BY87-90) and for BKD (BY87 and BY90). Inclusions indicative of EIBS were not detected in any brood year. Clinical BKD was not observed in BY87, but Rs bacteria were detected by fluorescent antibody technique (FAT) in 4 out of 20 fish. FAT slides from BY90 fish have not yet been read.

Summary

1. The routine monitoring of the health of hatchery stocks determines which fish pathogens and/or management practices are compromising fish health, and gives some indication of how to better manage the fish to avoid disease outbreaks.

2. We have taken successful measures to reduce BGD, by discontinuing the use of well 4 during the critical rearing period, and BKD, by the use of erythromycin injection and gallimycin feeding, chilled incubation water, close monitoring of DI, and ELISA-based segregation in the LF fall chinook. We need additional chilled water capacity and continued use of ELISA, both for segregating progeny and to aid in evaluating the effectiveness of other measures.

3. EIBS, the primary fish health problem for the spring chinook, was not detected in the two broods that had both reduced densities and warmer rearing water. Additional chilled water for incubation would also be beneficial for this program.

4. The lethal sampling of wild and natural outmigrants has been minimal. We hope to continue checking spring chinook outmigrants for EIBS and BKD, and sampling them to assess their condition.

References

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                          SUMMARY OF FISH AUTOPSY

LOCATION: Lyons Ferry Hatchery            QUAL. CONTROL INSPECT. NO.: NA

Species:  fall chinook    Autopsy Date: 4-15-92        Sample Size:        20
Strain:   Snake River     Age: BY90           Tissue Collection No.: NA
Mark/Lot: NA                                     Disease Survey No.: NA
Unit: Ponds 29 & 30       Water Temp.:  50 F       Case History No.: NA
Fish Source:   Lyons      Water Hardness:     NA ppm    Custody No.: NA
Egg Source:    Lyons      Investigator: Jerry&Kris
Hatching Date: NA         Reason for Autopsy:   Pre-release
Remarks:  Fed this morning.

==============================================================================
                                               STANDARD            COEFFICIENT
                            MEAN               DEVIATION           OF VARIATION
    Length               176.450 mm             17.97 mm                  10%
    Weight                63.080 gr              16.1 gr                  26%
    Ktl*                   1.150                 0.17                     15%
    Ctl**                  4.155
    Hematocrit            48.750                 2.95                      6%
    Leucocrit              0.050                 0.22                    436%
    Serum Protein          4.870                 0.57                     12%
 *Expressed as Ktl times 10 to the fifth power
**Converted from Ktl; expressed as Ctl times 10 to the fourth power
==============================================================================
                      VALUES AS PERCENT OF TOTAL SAMPLE

                 PSEUDO-              MESEN.             HIND
 EYES     GILLS  BRANCHS   THYMUS      FAT     SPLEEN     GUT     KIDNEY LIVER     BILE
N  100%| N 100%| N     90%|0  65%| 0  20%| B    0%| 0 100%| N 100%| A  0%| 0  15%
B1   0%| F   0%| S     10%|1  35%| 1  55%| R  100%| 1   0%| S   0%| B100%| 1  70%
B2   0%| C   0%| L      0%|2   0%| 2  20%| G    0%| 2   0%| M   0%| C  0%| 2  15%
E1   0%| M   0%| S&L    0%|x 0.4 | 3   5%| NO   0%| x 0.0 | G   0%| D  0%| 3   0%
E2   0%| P   0%| I      0%|      | 4   0%| E    0%|       | U   0%| E  0%| x 1.0
H1   0%|OT   0%|OT      0%|      | x 1.1 | OT   0%|       |OT   0%| F  0%|
H2   0%|       |          |      |       |        |       |       |OT  0%|
M1   0%|       |          |      |       |        |       |       |      |
M2   0%|       |          |      |       |        |       |       |      |
OT   0%|       |          |      |       |        |       |       |      |
------------------------------------------------------------------------------
                            Summary of Normals
       |       |          |      |       |        |       |       |      |
   100%|   100%|       90%|   65%|       |    100%|   100%|   100%|  100%|
------------------------------------------------------------------------------
                            Summary of Means
       |       |          |      |       |        |       |       |      |
       |       |          |  0.4 |   1.1 |        |   0.0 |       |      |   1.0
------------------------------------------------------------------------------
SEX:     M:  20% F:    80% U:   0%
==============================================================================
                              GENERAL REMARKS
FINS     NA

SKIN     NA

GONADS   NA

OTHER    Fork length measured.
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                       SUMMARY OF FISH AUTOPSY

LOCATION: Tucannon Hatchery                QUAL. CONTROL INSPECT. NO.: NA

Species:  spring chinook  Autopsy Date: 03-30-92        Sample Size:       20
Strain:   Tucannon        Age: BY90             Tissue Collection No.: NA
Mark/Lot: NA                                         Disease Survey No.: NA
Unit: single pond         Water Temp.:  45 F            Case History No.: NA
Fish Source:    Tucannon  Water Hardness:     NA ppm       Custody No.: NA
Egg Source:     Tucannon  Investigator: Tami/Jerry/Lance
Hatching Date: NA         Reason for Autopsy:   Pre-release
Remarks:  Fish 10 - 20 were fed.

==============================================================================
                                                STANDARD            COEFFICIENT
                          MEAN                  DEVIATION           OF VARIATION
    Length              137.200 mm                9.34 mm                   7%
    Weight               30.980 gr                7.25 gr                  23%
    Ktl*                  1.200                   0.06                      5%
    Ctl**                 4.335
    Hematocrit           47.890                   3.23                      7%
    Leucocrit             0.780                   0.42                     53%
    Serum Protein         6.820                   0.79                     12%
 *Expressed as Ktl times 10 to the fifth power
**Converted from Ktl; expressed as Ctl times 10 to the fourth power
==============================================================================
                      VALUES AS PERCENT OF TOTAL SAMPLE

                PSEUDO-              MESEN.           HIND
 EYES     GILLS  BRANCHS    THYMUS    FAT     SPLEEN   GUT     KIDNEY LIVER    BILE
N  100%| N 100%| N    100%|0   60%| 0    0%| B    0%| 0 100%| N 100%| A  0%| 0     5%
B1   0%| F   0%| S      0%|1   40%| 1   25%| R  100%| 1   0%| S   0%| B100%| 1    30%
B2   0%| C   0%| L      0%|2    0%| 2   50%| G    0%| 2   0%| M   0%| C  0%| 2    65%
E1   0%| M   0%| S&L    0%|x 0.4  | 3   25%|NO    0%| x 0.0 | G   0%| D  0%| 3     0%
E2   0%| P   0%| I      0%|       | 4    0%| E    0%|       | U   0%| E  0%| x 1.6
H1   0%|OT   0%| OT     0%|       | x 2.0  |OT    0%|       |OT   0%| F  0%|
H2   0%|       |          |       |        |        |       |       |OT  0%|
M1   0%|       |          |       |        |        |       |       |      |
M2   0%|       |          |       |        |        |       |       |      |
OT   0%|       |          |       |        |        |       |       |      |
--------------------------------------------------------------------------------
                               Summary of Normals
                       |          |       |        |        |       |       |      |
   100%|   100%|      100%|   60%|        |    100%|   100%|   100%|  100%|
--------------------------------------------------------------------------------
                               Summary of Means
       |       |          |       |        |        |       |       |      |
       |       |          |   0.4 |    2.0 |        |   0.0 |       |      |     1.6
--------------------------------------------------------------------------------
SEX:     M:   45% F:    55% U:   0%
================================================================================
                                GENERAL REMARKS
FINS      NA

SKIN      NA

GONADS    NA

OTHER     Fork length measured.
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                           SUMMARY OF FISH AUTOPSY

LOCATION: Tucannon smolt trap.           QUAL. CONTROL INSPECT. NO.: NA

Species:  spring chinook  Autopsy Date: 04-01-92      Sample Size:        20
Strain:   Tucannon        Age: BY90            Tissue Collection No.: NA
Mark/Lot: NA                                      Disease Survey No.: NA
Unit: NA                  Water Temp.:  NA  NA    Case History No.: NA
Fish Source:   natural    Water Hardness:    NA ppm      Custody No.: NA
Egg Source:    natural    Investigator: Lance&Jerry
Hatching Date: NA         Reason for Autopsy:   Baseline data.
Remarks:  Fish collected during out migration.

==============================================================================
                                            STANDARD             COEFFICIENT
                        MEAN                DEVIATION            OF VARIATION
     Length           100.550 mm              7.17 mm                  7%
     Weight            10.640 gr               2.4 gr                 23%
     Ktl*               1.050               0.04                       3%
     Ctl**              3.793
     Hematocrit        46.290               7.09                      15%
     Leucocrit          0.290               0.46                     157%
     Serum Protein      3.890               0.79                      20%
 *Expressed as Ktl times 10 to the fifth power
**Converted from Ktl; expressed as Ctl times 10 to the fourth power
==============================================================================
                        VALUES AS PERCENT OF TOTAL SAMPLE

                PSEUDO-                MESEN.               HIND
 EYES    GILLS  BRANCHS  THYMUS       FAT    SPLEEN      GUT     KIDNEY LIVER     BILE
N  100%| N 100%| N   100%|0  90%|0   90%| B   0%| 0  85%| N 100%| A  0%| 0    5%
B1   0%| F   0%| S     0%|1  10%|1   10%| R 100%| 1  10%| S   0%| B100%| 1   15%
B2   0%| C   0%| L     0%|2   0%|2    0%| G   0%| 2   5%| M   0%| C  0%| 2   80%
E1   0%| M   0%|S&L    0%|x 0.1 |3    0%|NO   0%| x 0.2 | G   0%| D  0%| 3    0%
E2   0%| P   0%| I     0%|      |4    0%| E   0%|       | U   0%| E  0%| x 1.8
H1   0%|OT   0%|OT     0%|      |x 0.1  |OT   0%|       |OT   0%| F  0%|
H2   0%|       |         |      |       |       |       |       |OT  0%|
M1   0%|       |         |      |       |       |       |       |      |
M2   0%|       |         |      |       |       |       |       |      |
OT   0%|       |         |      |       |       |       |       |      |
-----------------------------------------------------------------------------------
                               Summary of Normals
   100%|   100%|     100%|   90%|       |   100%|    85%|   100%|  100%|
-----------------------------------------------------------------------------------
                               Summary of Means
       |       |         |  0.1 |  0.1  |       |  0.2  |       |      |      1.8
-----------------------------------------------------------------------------------
SEX:   M:  30% F:   70% U:  0%
==============================================================================
                                GENERAL REMARKS
FINS    NA

SKIN    NA

GONADS  NA

OTHER   Fork length measured
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Bacterial Kidney Disease in Wild and Hatchery Spring and Summer Chinook Salmon Juveniles in the Snake River Basin

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Spring and summer chinook salmon *Oncorhynchus tshawytscha* stocks propagated in hatcheries of the Snake River basin are often infected with *Renibacterium salmoninarum*, the causative agent of bacterial kidney disease (BKD; Hauck 1990; Warren 1990). The infections can be detected in the tissues and body fluids of spawning adults, and in the tissues of juvenile fish up to the age at which they are released from the hatchery. Adverse environmental factors and certain hatchery rearing practices are believed to affect the severity of infection among infected stocks of salmonids (Austin and Austin 1987; Warren 1991). There is also evidence that spring and summer chinook salmon smolts migrating from the Snake River basin are infected with *R. salmoninarum* (Matthews et al. 1988; Pascho and Elliott 1989; Elliott and Pascho 1991; Sanders et al. 1992); these fish presumably acquire infections before release by either vertical (parent to progeny) or horizontal (fish-to-fish) transmission of the kidney disease bacterium. There is very little information, however, on the severity of BKD in any life stage of wild or naturally reproducing stocks of spring and summer chinook salmon (Chapman et al. 1991; Elliott and Pascho 1991).

The prevalence and levels of BKD in a stock of fish are usually evaluated by observing the presence and number of *R. salmoninarum* cells in smears from tissue samples by the fluorescent antibody test (FAT; Bullock and Stuckey 1975; Bullock et al. 1980). Most versions of the FAT are not quantitative and lack the sensitivity to detect subclinical infections (Cipriano et al. 1985; Pascho et al. 1989). More recently, serological tests that detect a soluble antigen fraction of *R. salmoninarum* have been reported, including the enzyme-linked immunosorbent assay (ELISA; Pascho and Mulcahy 1987; Turaga et al. 1987; Rockey et al. 1991; Pascho et al. 1991). The ELISA for BKD is a quantitative assay that can detect subclinical levels of infection. It can be modified into a semi-automated assay, capable of analyzing several hundred samples in a single day, while retaining the ability to recognize very low levels of *R. salmoninarum* infection.

During 1988 the U.S. Fish and Wildlife Service began a study sponsored by the U.S. Army Corps of Engineers to evaluate the effect of BKD on the survival of spring and summer chinook salmon stocks impacted by their juvenile fish transportation program (Pascho and Elliott 1989; Elliott and Pascho 1991). The transportation of juvenile fall chinook salmon *O. tshawytscha* and steelhead *O. mykiss* past Snake River and Columbia River hydroelectric dams has been beneficial for those two species, as evidenced by greater adult returns of transported fish compared to nontransported fish. In contrast, the adult returns of spring chinook salmon have remained low, regardless of whether the smolts were transported or not (Park 1985; Raymond 1988). Spring chinook salmon are very susceptible to infection by *R. salmoninarum*, and it is believed that BKD may be a significant factor in the poor survival of spring chinook salmon smolts (Matthews et al. 1985; Park 1985; Raymond 1988).

During brood years 1988 and 1989 a major objective of the transportation study was to segregate and rear specific egg lots from the spring chinook salmon being spawned at Dworshak National Fish Hatchery (NFH), Idaho (Elliott and Pascho 1991; Pascho et al. 1991). Spring chinook salmon egg lots were segregated on the basis of experimental evidence that the probability of vertical transmission of *R. salmoninarum* is related to the level of *R. salmoninarum* in the female parent (Evelyn et al. 1986). Egg lots were segregated into two groups, one originating from parents with undetectable or very low levels of *R. salmoninarum* infection (low-BKD group) and the other from egg lots originating from parents with very high levels of *R. salmoninarum* infection (high-BKD group). Each segregation resulted in groups of progeny fish with different BKD infection profiles. They were used to examine the role of BKD on the downstream migration and adult returns of transported and nontransported spring chinook salmon smolts. To monitor the adult returns from each BKD-level group, most of the fish were marked with coded-wire tags the fall before their release into the Clearwater River, a tributary of the Snake River in Idaho.

One of the other objectives of that study was to monitor during the entire out-migration the prevalence and levels of BKD in spring and summer chinook salmon smolts arriving at the transportation collection facilities at hydroelectric dams in the Snake and Columbia river basins. The majority of the monitoring on the Snake River was done at Lower Granite Dam. Tissues were taken from a subsample of the smolts collected for transportation and they were examined for the presence of *R. salmoninarum* infections by the ELISA.

The random sample of smolts arriving at the Lower Granite Dam collection facility included summer and spring chinook salmon smolts that originated from several state and federal hatcheries, or from wild or natural production areas in Idaho and Oregon. Approximately 20% of the smolts sampled for BKD testing had an identifying mark, either a coded-wire tag, freeze brand, or passive integrated transponder (PIT) tag. After the BKD analysis was complete, we could use those marks to trace of the origin of the fish, and to determine whether their BKD status could be correlated with an experimental hatchery treatment. Unfortunately, very little information could be obtained for smolts from wild or natural production areas because wild marked smolts accounted for less than one percent of the fish collected for testing.

Spring and summer chinook salmon parr in selected wild and natural production areas of Idaho were marked with PIT-tags to study their migration habits as smolts. In a separate objective of the transportation study, the prevalence of *R. salmoninarum* infection was measured in a small number of parr from each of several locations where the fish were being PIT-tagged.

This report summarizes the information provided by the elements of the transportation study that investigated the prevalence and levels of BKD in identifiable groups of hatchery and wild juvenile chinook salmon from the Snake River basin. The objectives of that aspect of the research included the brood stock segregation study at Dworshak NFH, Idaho, the monitoring of BKD in spring and summer chinook salmon smolts collected for transportation at Lower Granite Dam, and the analysis of tissues from wild or naturally produced spring and summer chinook salmon parr for BKD.

Methods

Prevalence and Levels of Renibacterium salmoninarum Infection in Juvenile Chinook Salmon

Spring chinook salmon reared at Dworshak NFH, Idaho, in the brood stock segregation study were sampled as smolts just prior to release from the hatchery. Sixty fish were sampled from each BKD-level raceway in 1990 (1988 segregation) and 1991 (1989 segregation). A daily subsample of 20-25 fish from the spring and summer chinook salmon smolts arriving at Lower Granite Dam on the Snake River was taken by personnel from the National Marine Fisheries Service between early April and early June of each smolt out-migration; the daily subsample was increased to 50 fish for approximately 10 d during the peak smolt out-migration. Data are presented for the BKD testing of hatchery smolts that could be placed in the following categories on the basis of identifying marks: fish rearing density, age at release from the hatchery, and fish migration distance from the hatchery to Lower Granite Dam, Washington. At least 25 smolts were tested from each subgroup reported in a category.

Spring and summer chinook salmon parr were sampled from tributaries of the Salmon River, Idaho, each summer during the period 1988-1991. Valley Creek (sampled 1988-1991) and Chamberlin Creek (sampled 1991) are tributaries of the main stem, the Secesh River (sampled 1988-1991) is a tributary of the South Fork, and Marsh Creek (sampled 1989-1991) is a tributary of the Middle Fork. Approximately 60 parr were sampled from each location during a given year.

Processing and BKD Testing of Fish Tissues

Tissues from individual smolts collected at Lower Granite Dam or from the brood stock segregation raceways of Dworshak NFH, and three-fish pools of the parr from each wild or natural production area were processed and tested by the ELISA for BKD as described by Pascho and Elliott (1989), or the modified ELISA for BKD described by Elliott and Pascho (1991).

The *Renibacterium salmoninarum*-positive samples that had ELISA absorbances between one unit above the positive-negative cutoff absorbance and 0.199 were considered to have low infection levels, those with absorbances of 0.200-0.999 were considered to have medium infection levels, and those with absorbances ≥ 1.000 were considered to have high infection levels.

Results and Discussion

Brood Stock Segregation

The monitoring of the juvenile fish for BKD indicated that the brood stock segregation procedure had established groups of fish with significantly different patterns of BKD infection. The prevalence and levels of BKD and the mortality during rearing were consistently greater among the progeny in the high-BKD group. The impact of BKD was significantly less among the progeny in the low-BKD group, even though the fish in both groups were reared in untreated Clearwater River water; the river contains resident salmonids that may be infected with *R. salmoninarum* and could shed the bacterium into the water supply.

The BKD profiles of the prerelease smolts reared from brood year 1988 egg lots indicated that there were significant differences in the levels of *R. salmoninarum* infections in fish of the two BKD-level groups (Figure 1). Among the fish tested from the low-BKD group, only 1% (2/210) had medium to high *R. salmoninarum* infection levels. In contrast, 39% (81/210) of the smolts from the high-BKD group had medium to high infection levels.

Although similar trends were seen when the *R. salmoninarum* infection levels were measured in the prerelease smolts from the 1989 brood year, the magnitude of the differences was less than that between the BKD-level groups of the 1988 brood year. Among the fish tested, 42% (89/210) from the low-BKD group and 68% (142/210) from the high-BKD group had medium to high infection levels. The analysis of the BKD profiles for each of the three raceways within a BKD-level group revealed that approximately 50% of the smolts with medium to high infection levels in the low-BKD group came from a single raceway. Subgroups of fish from each raceway were also evaluated to provide a broader fish health profile for each BKD-level group. These data provided evidence that BKD may have been spread or exacerbated among the fish in that raceway during the application of coded-wire tags. At release, a large number of smolts were observed to have exophthalmia in one eye and an inflammation in the corresponding naris. A histological examination of tissues from these fish revealed *R. salmoninarum* infections in the affected eyes and nares. *Renibacterium salmoninarum* infections could not be detected histologically in the other organs or tissues of the same fish.

The spread of *R. salmoninarum* by the coded-wire tag apparatus may be an unavoidable consequence of the design of the equipment. These data suggest that further investigations are needed to measure the actual impact of tagging in spreading or aggravating infectious diseases among hatchery fish.

Spring and Summer Chinook Smolts Sampled at Lower Granite Dam

Fish rearing density.—Another hatchery practice that might have an effect on the losses from BKD is the density at which fish are reared. Increasing the density of fish in a raceway may eventually cause stress in the fish and make them more susceptible to pathogens, including the kidney disease bacterium.

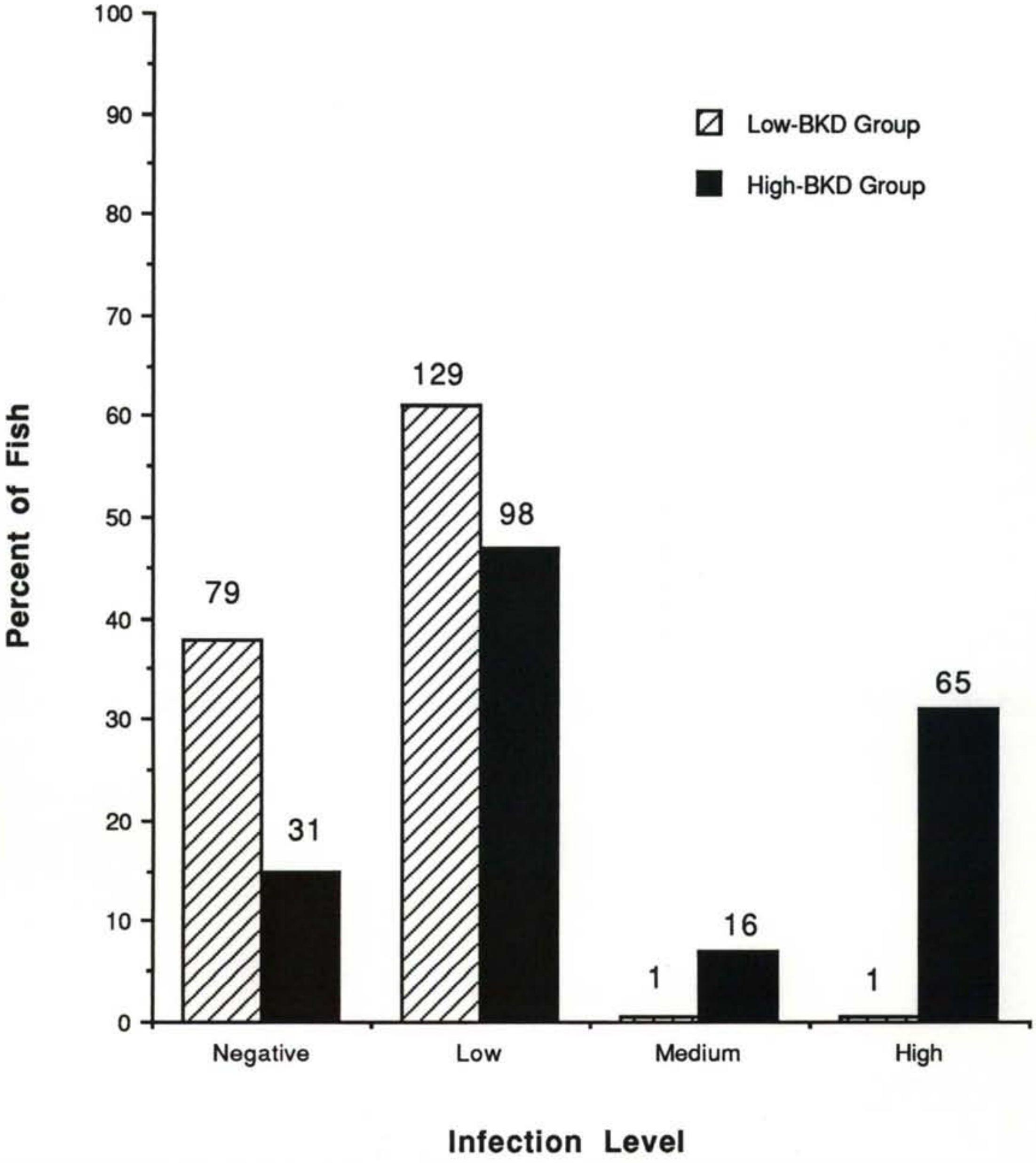

Figure 1. Distributions of ELISA OD values for random samples of spring chinook salmon smolts (1988 brood year) taken from low-BKD and high-BKD groups at Dworshak National Fish Hatchery during March 1990 just prior to their release. The numbers above the bars are the number of fish in each infection level category.

During 1989, personnel at Dworshak NFH and the Idaho Fishery Resource Office began a study to examine the effects of fish rearing density on the relative survival of groups of spring chinook salmon. Progeny from the 1989 brood year at Dworshak NFH were reared at densities of 15,000 fish per raceway (low density), 30,000 fish per raceway (medium density), and 45,000 fish per raceway (high density). Fish were marked with PIT-tags or coded-wire tags to measure their differential survival as smolts to Lower Granite Dam, and as returning adults to the hatchery. The monitoring element of the transportation study intercepted 95 smolts from these groups and their tissues were analyzed for *R. salmoninarum* infection.

There were no significant differences in the prevalence or levels of *R. salmoninarum* among the smolts tested from the three rearing density groups (Figure 2). A proportion of the smolts tested in each group had no detectable *R. salmoninarum* antigen and were rated as BKD-negative. This BKD-negative group included 13% (4/30) of the fish in the low-density group, 16% (6/38) of the fish in the medium-density group, and 4% (1/27) in the high-density group. None of the fish produced ELISA absorbances indicative of a high level of *R. salmoninarum* infection. An unexpected result was the absence of fish from the high-density group with medium or high levels of *R. salmoninarum* infection.

If the rearing density affected the prevalence and severity of *R. salmoninarum* infections, one would expect that the distribution of infections for the high-density group would be shifted to the right (toward the medium- and high-infection-level categories). The similarity of the infection-level distributions among these groups may be the result of other factors, such as the feeding of erythromycin during rearing or the levels of *R. salmoninarum* in the adults that provided eggs for this experiment. In 1989, egg lots from adults with very high or very low levels of *R. salmoninarum* infection were being concurrently selected for a brood stock segregation study, which meant that the egg lots remaining for the fish rearing density study were probably from parents with low to medium *R. salmoninarum* infection levels. This may have moderated the vertical transmission of *R. salmoninarum* and the subsequent severity of infection among the progeny. The analysis of tissues from fish in these groups by the ELISA during February and March of 1991 suggested that the BKD-profiles among the raceways tested were very similar (reported by the Dworshak Fish Health Center; data not shown). In contrast, when our laboratory measured the prevalence and levels of *R. salmoninarum* infection among spring chinook juveniles in an earlier, but similar, rearing density experiment (Carson NFH, Washington, on the lower Columbia River), the severity of infection was significantly higher among the fish in the high-density group. It may not be possible to isolate the role of one factor, such as fish rearing density, when describing the impact of BKD on hatchery salmonids.

Age at release.— Spring chinook are reared for over one year in the hatchery and many believe that this lengthy stay contributes to the development of severe BKD. Because this disease is slow to develop, the longer these fish are reared in the hatchery, the greater is the chance for the disease to be expressed.

One alternative is to accelerate rearing and release the fish from the hatchery a full year before they would be released under conventional rearing conditions. For example, a spring chinook salmon smolt released in 1988 would normally have been from the 1986 brood year (yearlings), whereas an early release fish would be from the 1987 brood year (0-age). During the 1988 and 1989 smolt migrations, several of the spring and summer chinook salmon smolts analyzed for BKD were identified as part of early release studies. Spring chinook salmon smolts analyzed for BKD in 1988 included some that originated from Dworshak NFH and Irrigon State Fish Hatchery (SFH), Idaho. (The Irrigon SFH fish were released from Lookingglass SFH, Idaho.) The Dworshak NFH smolts were 0-age and yearling fish, and those analyzed from Irrigon SFH were only 0-age fish. Among the smolts from Dworshak NFH, the severity of *R. salmoninarum* infections was higher in the 0-age fish. Approximately 59% (20/34) of the 0-age fish had high levels of *R. salmoninarum* infection, and none of the fish released as yearlings from Dworshak NFH had similar levels of infection. The 0-age fish released reared at Irrigon SFH had a distribution of *R. salmoninarum* infections very similar to that of the yearlings from Dworshak NFH.

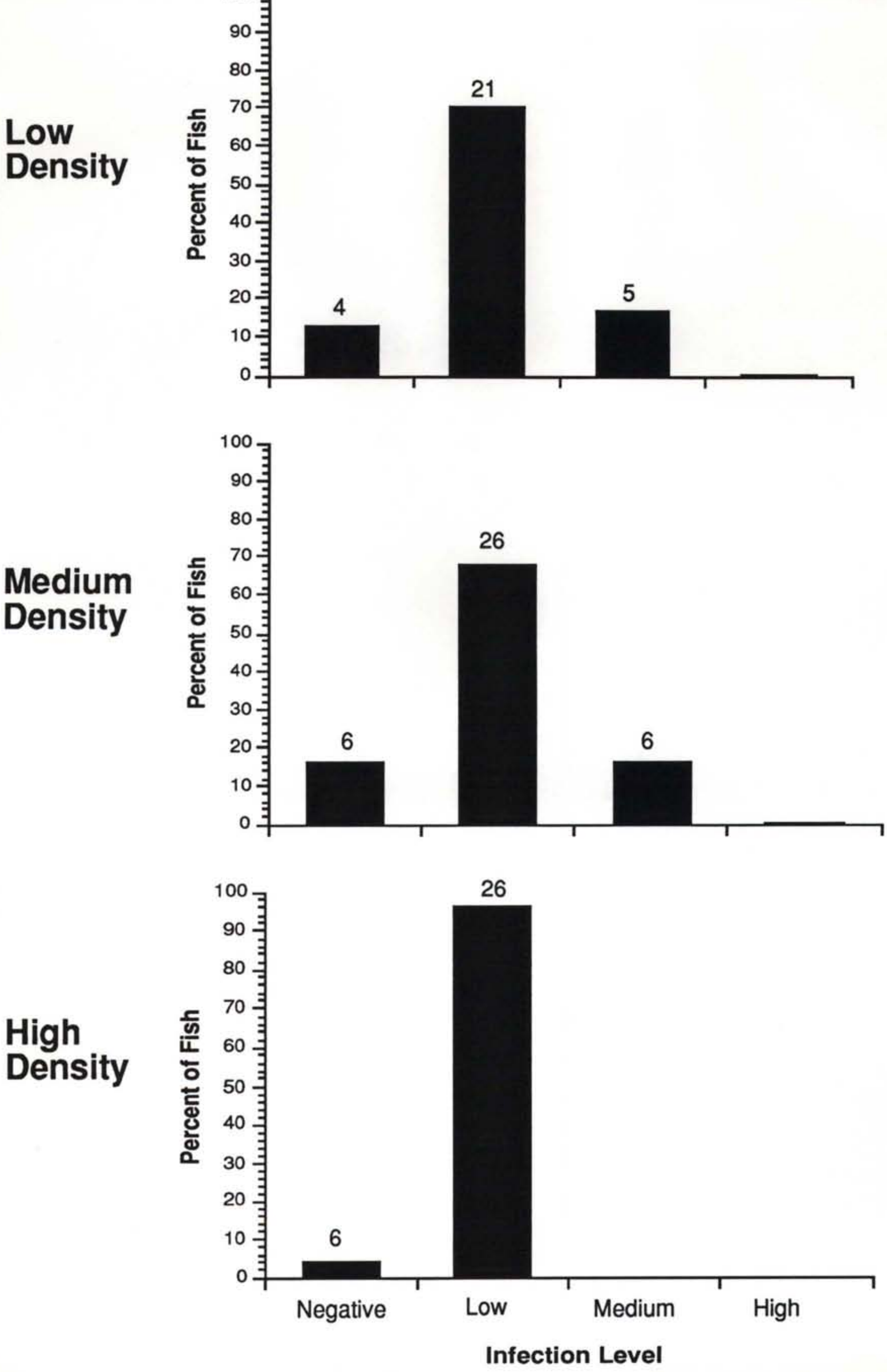

Figure 2. Distributions of ELISA OD values for spring chinook salmon smolts (1989 brood year) from the rearing density experiment at Dworshak NFH, Idaho that were intercepted at Lower Granite Dam during the 1991 out-migration. The numbers above the bars are the number of fish in each infection level category.

In the 1989 analysis of spring chinook salmon smolts from Dworshak NFH and Irrigon SFH, both yearling and 0-age fish from each hatchery were intercepted for BKD analysis. The ELISA data indicated that there were smolts with very high *R. salmoninarum* infection levels in each group of fish from a given hatchery. The greatest percentage (46%) of severely infected fish were found among Dworshak NFH yearling smolts (24/52), compared to 12% (5/42) of the Dworshak NFH 0-age smolts, 2% (1/46) of the Irrigon SFH yearling smolts, and 7% (6/77) of the Irrigon SFH 0-age smolts. There was a small percentage of BKD-negative fish in each group except the 0-age fish from Irrigon SFH. Interestingly, the yearling spring chinook salmon from Dworshak NFH were from the same stock and brood year (1987) as the subyearlings intercepted from this hatchery during the 1988 out-migration; both groups showed a high percentage of severely infected fish.

These data demonstrate that even within a hatchery there can be variation in the *R. salmoninarum* infection levels among different groups of fish, suggesting that the effect may be related to stock or to brood year. The presence of fish with severe infections among some groups of 0-age spring chinook, despite their short stay in the hatchery, suggests that vertical transmission is more important than horizontal transmission in at least some situations.

Migration distance to Lower Granite Dam.—Matthews et al. (1988) reported that many of the marked spring and summer chinook salmon smolts arriving at Lower Granite Dam late in the 1987 out-migration, a time when the prevalence of BKD was also highest, originated from hatcheries that were a relatively long migration distance from the dam. Although it would be easy to perceive these data as evidence for a correlation between the distance a stock of fish must migrate to Lower Granite Dam and the prevalence of BKD among those fish when they arrive at the dam, these authors noted that other factors related to the disease and smoltification of an infected fish may be responsible for this apparent association. For example, a hatchery salmonid smolt that became infected with *R. salmoninarum* before release and from a hatchery distant from Lower Granite Dam would have more time to develop a detectable infection during migration than one released from a hatchery near the dam.

When the tissues from yearling smolts arriving at Lower Granite Dam during the 1988 out-migration were analyzed for BKD (Pascho and Elliott 1989), the results suggested a pattern similar to that observed by Matthews et al. (1988). *R. salmoninarum* infection prevalences for the 1988 study were: Dworshak NFH spring chinook salmon 77% (40/52; 72 river miles to Lower Granite Dam), Lookingglass SFH spring chinook salmon 61% (45/71; 149 river miles), McCall SFH summer chinook salmon 96% (70/73; 285 river miles), and Sawtooth SFH spring chinook salmon 96% (24/25; 466 river miles). Unfortunately, when the prevalence and *severity* of *R. salmoninarum* infections were analyzed together, the picture was less clear because of the Dworshak NFH 0-age spring chinook salmon smolts described above. Among the yearling chinook tested in 1988, the sample from McCall SFH contained summer chinook salmon smolts with very high *R. salmoninarum* infection levels: 7% (4/73) of the fish were severely infected. The presence of high-infection-level fish in this sample fits the migration distance hypothesis. However, the 0-age spring chinook salmon smolts from Dworshak NFH, the closest hatchery to Lower Granite Dam, had an overall prevalence of *R. salmoninarum* infection that exceeded 88% (30/34); 59% (20/34) of the fish in that group had high infection levels. In contrast, the sample of 0-age spring chinook salmon collected at the dam in 1988 from a group reared at Irrigon SFH and released from Lookingglass SFH had a relatively low prevalence of infection (63%, 37/59), and no fish with high *R. salmoninarum* infection levels. Inconsistencies relative to the migration distance hypothesis were also found among the normal production (yearling) chinook salmon smolts analyzed from the 1988 out-migration (data not shown).

Spring and Summer Chinook Salmon Parr from Wild and Natural Production Areas

The ELISA analysis for BKD of the tissue pool samples from spring and summer chinook salmon parr taken from the Secesh River, Valley Creek, and Marsh Creek suggested that the prevalence of *R. salmoninarum* in these populations may be very high (Figure 3), possibly ranging from 92% in 1991 at Valley Creek and

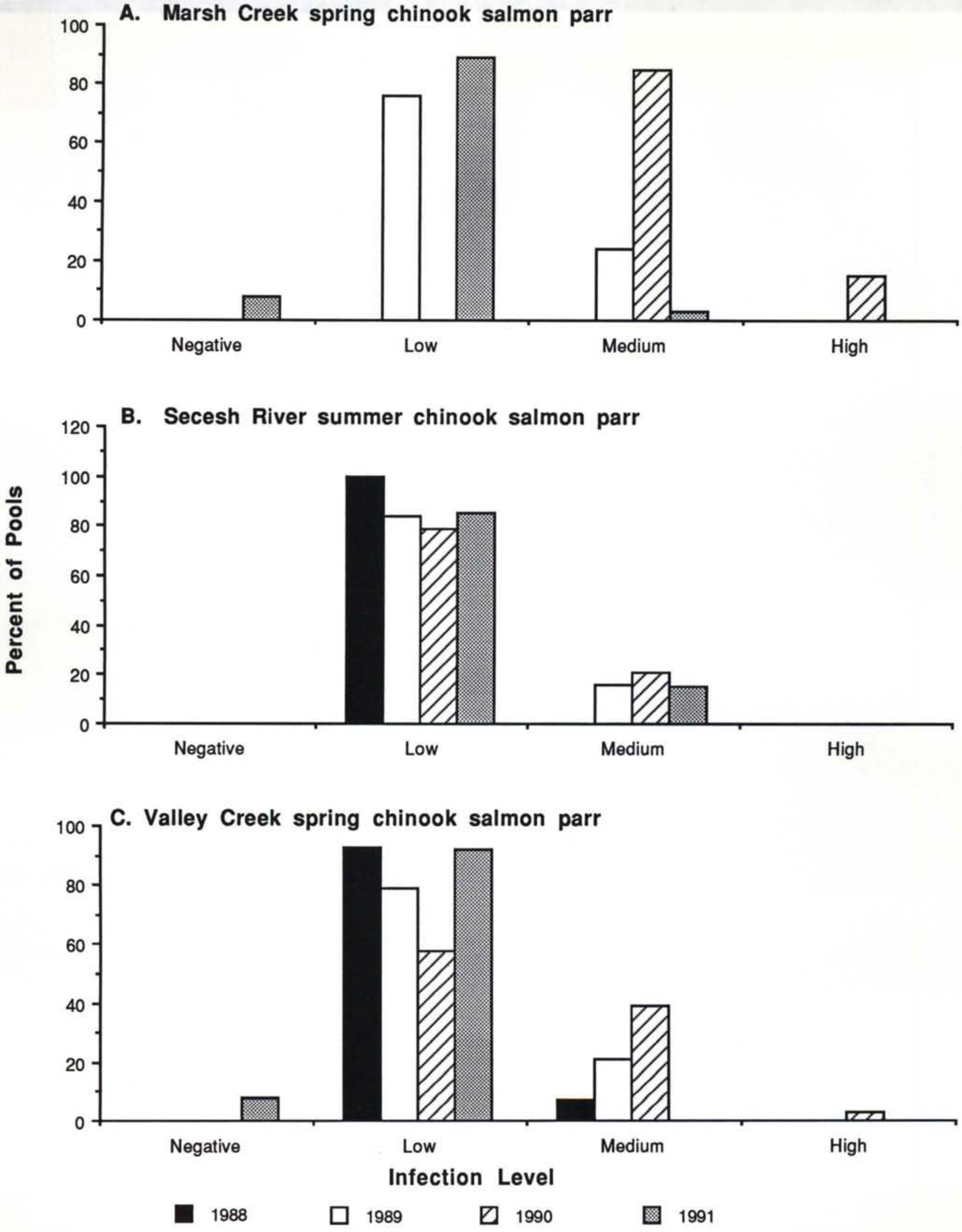

Figure 3. Comparison of the distributions of *Renibacterium salmoninarum* infection levels for spring and summer chinook salmon parr sampled from wild/natural production areas in Idaho in 1988, 1989, 1990, and 1991. The samples were processed as 3-fish pools because of the small size of the fish.

Marsh Creek, to 100% at all locations during the other years. In general, the majority of the tissue pools produced ELISA absorbances indicative of low *R. salmoninarum* infection levels, except in 1990 when 100% of the tissue pools from Marsh Creek produced absorbances that corresponded to medium to high infection levels. This is particularly important because Marsh Creek is one of the production areas most removed from hatchery influence. During 1991, the first tissue pools from spring chinook salmon parr sampled in Chamberlain Creek, another remote production area, were analyzed for *R. salmoninarum* antigen. The distribution of *R. salmoninarum* infection levels was similar to that for other locations during 1991; 91% of the tissue sample pools were positive for *R. salmoninarum* antigen, although most produced ELISA absorbances that corresponded to low concentrations of antigen (Figure 4).

These data cannot be directly compared with the ELISA data presented for the spring and summer chinook salmon smolts captured at Lower Granite Dam. The strength of this comparison is reduced because of the use of pooled tissue samples to analyze the parr for *R. salmoninarum* infections. The apparent prevalence of infection can become skewed because the presence of tissues from even one fish infected with *R. salmoninarum* in a tissue pool makes the entire pool positive. In addition, our past research has shown that the severity of *R. salmoninarum* infection among salmonids can vary by the life stage, and the prevalence or levels of infection at an early life stage (such as the parr stage) cannot be used to forecast the impact of the disease as the fish mature. Clearly, studies are necessary to measure the prevalence and levels of *R. salmoninarum* infection in spring and summer chinook salmon smolts during their migration from wild and natural production areas of the Snake River basin.

Summary

1. A very high proportion of the hatchery chinook salmon smolts leaving the Snake River basin are infected with *Renibacterium salmoninarum*.

2. The prevalence and levels of *R. salmoninarum* in hatchery chinook salmon smolts can be affected by hatchery rearing practices. Of equal importance may be the variations in the severity of BKD relative to the stock of fish and the brood year from which a specific group of fish originated.

3. Chinook salmon parr in wild and natural production areas of the Snake River basin are infected with *R. salmoninarum*.

4. Additional research is necessary to determine the prevalence and levels of *R. salmoninarum* infection in spring and summer chinook salmon smolts migrating from wild and natural production areas of the Snake River basin.

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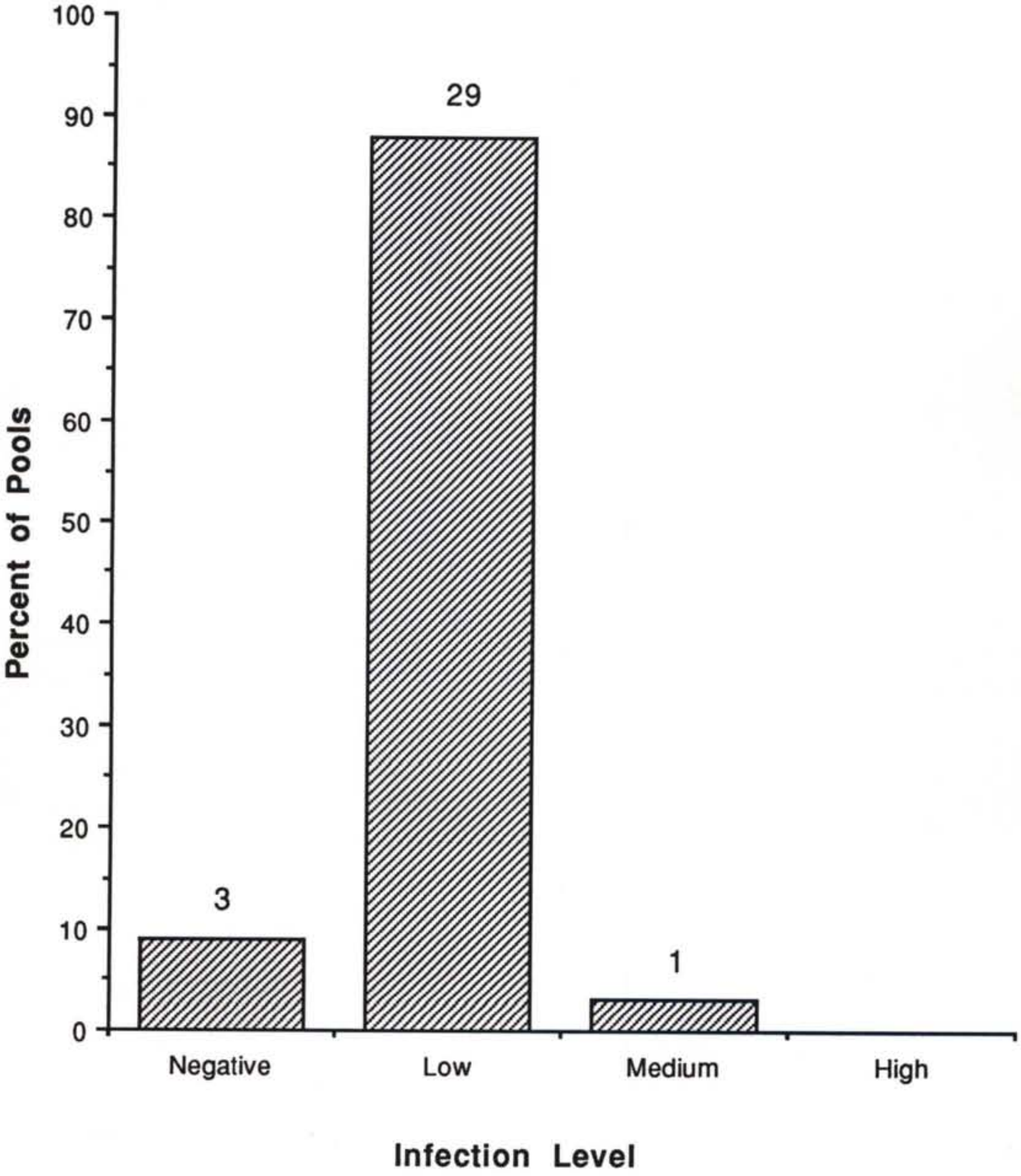

Figure 4. *Renibacterium salmoninarum* infection levels for spring chinook salmon parr sampled during the summer of 1991 from Chamberlain Creek, a tributary of the Salmon River, Idaho. These samples were processed as 3-fish pools because of the small size of the fish. The numbers above the bars are the number of pools in each infection level category.

Session Summaries by Facilitators

Wild and Hatchery Spring, Summer, and Fall Chinook: Migration Timing and Survival from Upriver Reaches

Bill Miller, Facilitator

Our group tried to give you the most recent data on hatchery and wild chinook migrations and timing. We've found is that there are differences between hatchery and wild chinook. The spring, summer, and fall wild/natural fish arrived at Lower Granite later and over a more protracted period than the hatchery fish. The question comes up: Is the water budget really helping wild fish? I think there was another question that wasn't stated: Pascho brought up the information about bacterial kidney disease (BKD) being higher in later fish. Is this an area that we should be concerned about with wild fish? Russ Keifer pointed out that small freshets move fish out of the smaller tributaries into the main-stem rivers in the fall and during the summer. Ed Buettner talked about flow correlation with migration rates through the reservoir. For fall chinook we pointed out that we really didn't know the effect of flow; it's probably an area we need to look at.

We also looked at the water budget and how it affected fall chinook; it seemed to have missed the wild ones. We discussed the use of PIT tags. PIT tags are an excellent tool for looking at arrival times and migration rates and I think that's why we have the data that we have to date on some of these stocks. Russ Keifer raised a red flag on using PIT tags for quantitative information. I think others have also questioned the use of PIT tags for quantitative information, particularly with small fish. Possibly predation or some other losses are different in PIT tagged fish.

Some genetic issues were brought up indirectly from the fact that Upper Salmon River spring chinook behaved differently as far as arrival times and moving out of the streams in comparison with fish from Crooked River, a lower tributary from the Clearwater. Rich Carmichael brought out some information that showed hatchery fish he was releasing from Imnaha and up in the Lookingglass area grew very little from the time of release down to the dam even though they were in the river for up to 40 days. Are these fish feeding? Is there a lack of food? I think these are good questions. Rich also reported that size at release had little effect on migration time and survival to Granite. Some other folks pointed out that larger is better. I think we've seen that for steelhead, but there is still some question on chinook.

Sources of Mortality in Reservoirs

Tony Nigro, Facilitator

Our session addressed what we know, what we don't know, and what we're doing to address the unknowns about three possible sources of juvenile salmonid losses in reservoirs during out-migration. These sources are predation, gas supersaturation, and residualization. I'm going to list three or four things that we think we know about these areas, three or four things that we think we don't know about these areas, and highlight what current efforts exist to address the unknowns in each of these areas.

First, what do we know about predation? Well, we know that losses to predation are large in at least some reaches of the Snake and Columbia rivers, and that these losses may reflect the true magnitude of reservoir mortality in the system. We know that although predation losses to some degree may be manifestations of the effects of other detriments to juvenile salmonids, such as injury, disease, stress, delay, gas supersaturation, etc., predation losses do include fit fish that would otherwise have survived the rigors of out-migration. This is especially likely because three out of every four fish lost to predation are eaten in the reservoirs, far away from the projects. We also know that predation losses may be reduced by reducing the numbers of predators, and by reducing predator-prey encounters. Reducing numbers doesn't necessarily mean eradication. But programs are in place that exploit predators at levels that should at least theoretically reduce their populations. Reducing predator-prey encounters offers greater challenges. There are some immediate applications that are worth trying in that arena, as evidenced by the development of criteria for the siting of smolt bypasses to minimize encounters. Another example of predator-prey encounter reduction measures is work on developing strategies for hatchery operations and releases that increase fitness and reduce encounters.

What don't we know about predation? Well, we don't know the proportion of fish lost to predators that would have died anyway. I don't think there is any doubt that the total number of fish lost to predators includes fish that would have died from other causes. We don't know the responses of the predator community to changes in numbers and structures of populations within their community. Does reducing numbers or altering structures of one predator population simply make room at the table for those that remain in the river? We don't know the responses of the predator community to changes in numbers or composition of the prey. Will enhanced survival through gauntlets such as tailraces simply be offset by corresponding increases in predation in the reservoir? Do the increases in alternate prey like shad offer potential buffers for juvenile salmon? What's currently being done to address unknowns regarding predator work? Well, presently, key information needs are being addressed to some degree by the Fish and Wildlife Service and by the Oregon Department of Fish and Wildlife. This work is in the context of frameworks developed by regional groups such as the fish passage advisory committee and its predecessor, the reservoir mortality technical work groups. It's focusing on collecting the empirical data necessary to track predator and prey community responses to predation control measures.

Moving on to gas supersaturation, what do we know here? Well, we know that spill is the main cause of gas supersaturation in reservoirs. We know that gas supersaturation is less of a problem now than it was historically because we've reduced spill and reduced plunge pool depths by installing deflectors. We know that proposed drawdowns will cause high levels of gas supersaturation if the spills exceed 50 kcfs, and if spill deflectors are rendered ineffective.

What don't we know about gas supersaturation? We don't know if travel time is reduced and survival is improved due to drawdown. Gains could be offset by losses to gas bubble disease. We don't know how far downstream high levels of gas supersaturation persist. We don't know the effects of gas supersaturation on resident fish. And we don't know the interactions between gas supersaturation and other sources of mortality, such as predation. What's presently being done in this area? During our session, it wasn't clear that any current work is investigating unknowns related to the proposed drawdown and possible problems with gas supersaturation.

Finally, what do we know about residualization? Well, we know very little about the causes of residualization. We also know that residualization does not receive much attention from researchers. It has not been perceived by the region as much of a problem, at least in priority. What don't we know about residualization? Well we don't know the degree of residualization in any of the Columbia and Snake River reservoirs. We don't know the effects flow conditions have on the occurrence of residualization. We don't know the physiological causes or triggering mechanisms, and we don't know the fate of fish that residualize but are subsequently flushed from the system. What's being done in this area? It appears that presently some data is being generated incidental to other work on mechanisms of smoltification and occurrence of residualization upstream of Lower Granite Dam.

In conclusion, it's apparent that any measures we undertake to reduce reservoir mortality all suffer from the same limitations with regard to evaluating their efficacy. There is presently no regionally accepted protocol for measuring survival with the precision necessary to detect changes that may occur over time. Even if we do eventually make precise measures of survival, we probably will never be able to apportion the incremental changes in survival that we see among the myriad measures concurrently undertaken in the basin to improve survival. Having said this, it's crucial that modelers take the challenge to help us put these measures in perspective relative to their potential benefits.

Factors Affecting Migration Rates and Survival through Reservoirs

John Williams, Facilitator

There is really no consensus about the factors affecting migration rates and survivals. A few people talked about factors affecting migration rates through reservoirs, and to a large degree this was based upon what we know about hatchery fish. Some of the work that was done at Dworshak hatchery showed specifically that the smoltification of the fish affects travel rates through the Lower Granite Reservoir. We know from data on fish released from the Lewiston trap and recovered at Lower Granite Dam that the travel time was largely dependent upon the degree of smoltification of the fish, although there was some response to flow. What we don't know is what the mix of wild and hatchery fish is. The mix of hatchery and wild fish has changed over the years from 100% wild back in the early sixties down to presumed 95% hatchery these days. So conclusions are difficult because in some cases information from the hatchery fish has nothing to do with the wild component, or what we should do to bring back the wild fish. We know that the majority of the hatchery fish come through the Lower Granite Reservoir earlier than the majority of the wild fish.

We do know that the hatchery fish delay in Lower Granite Reservoir for some time. We don't know what effect that has on the survival of fish in the reservoir or on the survival of wild fish that go through the reservoir. And yet a tremendous amount of effort has been put into developing models that consider just one parameter—flow. People have used the Simms-Ossiander relationships on flow and survival from the 1973 through the 1979 period to predict what responses we will get when we have changes in flow. The correlative models do not have in them, unfortunately, other factors that affect or that are related to fish condition. And we've now gone back to begin to look at some of the old data and to consider how conditions at the dams have changed. Those of you who are here heard the discussions between Charlie Petrosky and Gene Matthews. Gene knew all of those fish back in the 1970s, they were all his friends. And those that were descaled, he felt badly about. Descaling levels were very high then and that probably had a tremendous impact on the survival of fish to Bonneville Dam. And even though the flows were low, when you have a 48-hour delayed mortality of marked fish of 40%, probably the expectations that those fish would survive to Bonneville Dam, whether you had a high flow or low flow, is not very great.

Jim Anderson has attempted to develop mechanistic models to predict survivals, but his methods don't predict the kinds of survivals that we got in '73 and '77. That's not to say that flow probably isn't a very important factor. But we don't have a very good idea about other factors such as interactions of wild and hatchery fish in the reservoirs and how the hatchery fish may or may not affect the survival of the wild fish so we can't say too much about it. Earl Weber and co-workers have attempted to put together some models to make predictions about the survival of summer fish in the river and it has to be a new mechanistic process because we just don't have any historic data on that. It's probably a real gap in what we know about the system. And what can we do for the fall chinook that are down to such low levels? We don't have a very good baseline other than that they've gone down tremendously.

Finally, I want to make the point that we've given little attention to the importance of the estuarine and marine systems. How have the changes in discharge patterns brought about by the hydropower system affected the survival of the fish when they make it to the ocean? How has the lack of turbidity in the water as compared to what it was historically affected the fish's ability to make the transition to seawater and to avoid predation and some other kinds of things? It's an issue which has not been addressed to any great degree. It may have an effect on the overall survival.

Effects of Turbine and Bypass Passage

Jim Athearn, Facilitator

In our group we talked about passage of juvenile salmonids past the dams, and we particularly focused on the tailrace area and some considerations for siting. We talked about some new nonlethal technology for evaluating passage, and Steve Grabowski talked specifically about new research on extended-length fish-guiding devices. Earl Dawley presented some surprising results of the relative survival evaluations at Bonneville Dam. Matt Mesa discussed the finding that the northern squawfish prefers dead to live prey. Matt found descaling had little effect on vulnerability to predation and yet the physiological responses indicated that descaling may be more important than previously thought. He felt that the relationship between clinical indicators of stress and predator avoidance ability is still unclear. The use of high water velocities to reduce or exclude predation around bypass outlets is very promising. For future activities, he thinks that comparing predation rates on BKD-infected vs. uninfected fish and naive vs. conditioned fish is important. In terms of siting outfalls, Rock Peters discussed the application of information specifically to the situation of The Dalles. Both Peters and Dawley suggested criteria for outfall siting: high water velocities, long distance from release sites to shorelines, possibly a period of orientation after egress from the bypass, dispersal to lower densities prior to encountering locations where there may be squawfish or other predators, and releasing fish at times when predator activity is at its lowest. Rob noted that the design of the outfall system must have flexibility to allow for changes as we get new information and that all of the bypass systems that are installed should be evaluated. At The Dalles, during the summer when there are mid and low flows, the suggested velocity criteria can't be met. This raises the question: What do you do when your best science tells you the criteria can't be met? You have to make some choices. Other methods that Rock suggested included multiple bypass outlets and short-haul transport.

Bob Stansell discussed nonlethal means of monitoring smolt passage, including hydrocoustics. He noted that hydrocoustics has some advantages, including long-term continuous and multiple-site sampling. On the other hand, you can't identify species or put confidence limits on the estimates. Additionally, they found that the hydrocoustic estimates compared favorably with the fish guiding efficiency (FGE) estimates. Other new technologies include split-beam hydrocoustics, which allows low sampling volume and hopefully a better estimate. Laser-beam sampling technology may be even more accurate, but it is expensive.

Effects of Transportation

Teri Barila, Facilitator

The panelists in our section focused on data gaps and future research needs. Gene Matthews suggested that we need more precise estimates of the actual benefit of transport at various flow levels. We've never really been able to do this with past research. Along with that we would need specific reach survival estimates with similar precision so that we can more directly compare survival estimates for in-river fish against survival estimates for transported fish during the whole course of the out-migration. Perhaps one of the most significant areas is trying to get a better handle on the benefits of transportation for hatchery versus wild fish. We will actually be getting a little bit of that now with the scale-analysis work that NMFS is working on cooperatively with ODFW. Gene notes that a definitive study on homing would be valuable to provide a direct comparison between homing of transported and control groups using either PIT tags or radio tags. If there is a differential mortality occurring with transported fish, we'd like to know where that's occurring and perhaps now we can identify where it might be occurring. A final area concerns the bigger picture of the ecosystem and the impacts of the transport program in the estuary in terms of releasing large numbers of fish in a relatively short time. This is particularly true if we go into an extended transport program and begin to release the fish further out in the estuary. What are the impacts and is that of possible benefit or not?

The most basic question raised by Alec Maule with regard to the use of physiological stress indices was "what correlation exists between the short-term stress response of juvenile salmonids to collection, bypass, and transport and their long-term survival? Further, how would that relate to the stressors acting on in-river passage fish and their long-term survival? He notes that physiological responses of fish can be used as biological assessment tools to help evaluate the transportation system, and of course that is how we've used the data to date. God examples were brought up of improvements in project conditions that have helped to drastically reduce post-handling mortalities. New procedures for handling fish have been developed, such as the Little Goose open bypass. A third point concerned the possible interactions between stress, descaling, disease, and predation, and the effects on transported fish versus in-river passed fish. For in-river passed fish that must also include gas supersaturation effects. Would post-transport recovery of perhaps 24 hours prior to fish being released provide any additional benefit prior to fish being released? Again that's an area that we hope we will be able to begin to address with new research.

Diane Elliot raised a question concerning the role of BKD and other diseases in smolt mortality above Lower Granite Dam. Based on the recoveries at the dams of high-BKD and low-BKD fish released from Dworshak Hatchery, 25 percent more of the low-BKD fish were recovered than the high-BKD fish. What does the level of BKD infection mean in terms of long-term survival? What can a smolt tolerate in terms of BKD levels and still survive to maturity? How does transportation versus in-river passage affect that survival rate? And importantly, what is the BKD level in wild versus hatchery stocks and how does that affect transport or in-river passage conditions? Some of these identified research needs are being addressed through the needs and priorities process of the fish passage program of the Corps of Engineers (COE), and Bonneville Power Administration (BPA) has also identified some of these as program elements.

Disease and Other Factors Affecting the Health of Wild and Hatchery Smolts

Christine Moffitt, Facilitator

The take-home message from this session is that we know very little about what role disease is playing in losses of either hatchery or wild fish. It became abundantly clear from listening to the state pathologists that they have spent a lot of time monitoring in the hatchery and haven't been integrated into the management or research arms of these agencies. We need to integrate considerations of fish health into planning tagging operations so that the fish being tagged aren't impaired. We need to integrate existing fish-health laboratories that Bonneville has funded over the last four or five years into the research efforts on the Snake River. We need to look very carefully at hatchery management practices and recognize that releasing large numbers of juvenile fish does not necessarily translate into large numbers of returning adult fish. A wild or naturally produced fish is not free of disease. We must understand that pathogens are natural components of any ecosystem and that we learn to manage with them. The quality of the fish produced needs to be assessed continuously. Our program goals in the Snake River basin that are stated in terms of pounds of fish released or numbers of smolts released need to be re-evaluated. It may be beneficial to reduce rearing densities and eliminate some of these high-density rearing operations. The release strategies at the hatcheries need to be evaluated: we shouldn't need to clean out the hatcheries in early April, if those fish aren't ready to move, just because we've got more production coming on line. And the final point -- it was just a casual discussion, but worth bringing out here -- is the element of hatchery siting. So much of siting of hatcheries has been based on political and not biological basis. We're dealing with many hatcheries that have very poor water quality conditions and we need to improve this throughout the region and try to work together in an integrated fashion to produce a hatchery product that is going to work.

Discussion by Workshop Evaluation Panel

After the facilitators had completed their summaries, Jim Congleton introduced a panel of experts and asked them to summarize their impressions of the workshop. Jim introduced Doug Arndt (U.S. Army Corp of Engineers), Roy Bailey (Intertribe), Bert Bowler (Idaho Dept. of Fish and Game), Fred Olney (U.S. Fish and Wildlife Service) and Dick Whitney (Professor Emeritus, College of Fisheries, University of Washington).

DOUG ARNDT: When I first heard that we were having a workshop on smolt survival I got pretty excited, so I called Jim and asked if I could give a paper. He said, "No, to give a paper you have to be knowledgeable." Jim did say, however, that I could be on the evaluation panel because, there, all you had to do was wear a tie and sound knowledgeable. Well, I'm wearing a tie; whether I sound knowledgeable will be determined in a moment.

As I listened to the many papers over the last two days, I used a set of criteria to make judgements. They were: Are we doing good science here? Is it state-of-the-art, objective, and collaborative? And secondly, is it science that is relevant to the decisions that are now going on? I'm very pleased to say, "Absolutely" to both questions. Having worked on the Columbia for almost 20 years now, this is super, super stuff that is going on. There is one qualifier that I need to add, though. There was a strong undercurrent through some of the discussions of an either-or type of position. That is, you were either for hatchery or you were for wild fish. You were either flow or nonflow, you're transport or you're nontransport. But we're working in an ecosystem, and when I say ecosystem I mean from the little tributaries up in the Salmon River to the ocean, the black box ocean. Taking positions is basically nonconducive to the production of salmon. We're not dealing with a pristine ecosystem. As a result of that, there is not going to be a silver bullet that's going to get us out of the problems that we're in. It strikes me that what we're really looking at is a myriad of smaller actions that have to be undertaken, which taken together will allow us to reach whatever potential the system now has. In that regard too, I think I heard some defensiveness in some of the research reports. I think that that's a tendency that can be damaging. Usually when you build a car, you don't advertise the car before you run it through a pretty rigorous set of tests. You should be your own worst critic.

Secondly, is the science we're doing relevant, is the information we're gathering now influencing the decisions that are being reached, or are we simply recording history? To some extent we are influencing decisions: the recovery team has been here and they're hearing this good science, and hopefully we'll influence their decisions. Hatchery practices are, I know, being modified on the basis of some of the disease research, such as that Diane and Ron are doing. but the questions about overall system survival, ocean survival, it is those questions that we need science to answer, and for which we need data. Although funding agencies are giving vast amounts of dollars to conduct research on the long-term survival of fish, some of the data is going to be tough to get. We need data because the decision-making process is going to proceed with or without scientifically sound data. Scientists are going to take more risks and perhaps reach out for survival data. Beyond that, and in closing, I thoroughly appreciate the workshop: I thank Jim and the facilitators for their efforts. This sharing of information will benefit us all.

ROY BEATTY: I'm sorry to disappoint you; Phil Mundy was actually asked to be on this panel but he got word that some workshop participants were out trying to gather rotting produce from grocery stores in preparation for his talk this morning, and decided it would be better to have me up here. I'd like to thank Jim for giving me the chance to speak and for his overwhelming generosity in saying I had five minutes. Actually I feel very well qualified to speak here, having been a student of fishery science, business management, and theology, and it looks to me like all three apply here. To restate the obvious, this workshop is focused on the survival of juvenile chinook during their migration from freshwater rearing areas to the ocean. What I'd like to focus on is the out-migration; therefore you won't necessarily hear me talk about rearing or marine habitat. The river environment is influenced a great deal by human actions, and I think we need to focus our attention there, not on what's going on in the ocean, where we have little control. I'm going to make six points here: First of all, we're human. We're curious, we're mortal, and we're not omniscient, we don't know everything. Second point, we are working with animals and natural systems that are very, very complex and diverse. The objects of our study and interest will not fit tidily into the cubbyholes that we as scientists depend on to organize our knowledge. This is especially true for fish behavior, which has a great deal to do with how they survive through the system. How much do we know about how these fish behave and why they behave the way they do? We've seen examples during this workshop of a great deal of variability in the migration timing of juveniles, and this is just one example of variance in behavior. Russ Keifer discussed the fall movement of spring and summer chinook salmon out of tributary areas. That is contrary to the conventional wisdom that spring and summer chinook are spring migrants. Billy Connor pointed out that many subyearlings at Lower Granite in June were determined to be spring and summer chinook. We have to be careful we maintain our awareness of the variability in nature and how we manage for that. A good example is how we, probably inappropriately, try to induce uniformity in our hatchery products.

The third point I'd like to underscore is the importance of scientific information exchange. I think we have seen here in the last several days an excellent example of the way to share information. We also heard some comments on the importance of including some subjective anecdotal observations in reporting our results. The numbers that we see on paper can be easily misused or misinterpreted; we often don't understand the context and the process that generated those numbers. For example, Ron Pascho indicated that some numbers that he's reporting could be misinterpreted without knowing the influences on them. Gene Matthews has also conveyed some ideas about factors that have influenced transportation benefit ratios in the past years. We also see that several people are re-examining historical data, the data of Simms and Ossiander, for example. A second point under the need to exchange information is the need to develop ways of storing, sharing, and summarizing that information. I've learned a great deal here about things that had been going on for years that I had no knowledge of. I'm a relative newcomer to the basin, but it's clearly becoming harder and harder as research proliferates to keep everybody who needs to know in touch with what's being done. For example, I've run across numerous examples where agency reports are simply lost or not available. Another good example of why we need to develop better ways of managing information is that we'll find that what we're discovering now is not new. We will find that there is already a lot of information on when juvenile fish move. Paul Reimers, working on the southern Oregon coastal streams, has documented the influence of light conditions and moon stages on the movement on chinook fry, for example. I think one way that we may be able to provide for some of these needs is a network or a centralized center for information exchange. Either through electronic format, relatively new and the best way to handle many of our needs, and through hard copy.

My fourth point is that we need better quantitative tools for us to study survival. It looks like we're heading in the right direction, but are not there yet. We must continue to develop ways to measure juvenile passage survival as accurately and precisely as possible. Steve Pettit says what we may need is a smolt trap for the nineties. We may need some way of measuring smolt passage in large streams. Now it sounds like Russ Keifer has achieved some very good efficiencies at various times of the year in smaller streams. Can we partition survival out between the tributaries and head of the reservoir and the reservoir itself? Hydrocoustics may offer us a good way to monitor movement of fish without actually handling those fish. Bob Stansell's work on nonlethal FGE estimates are another good example of mechanical tools that may help us do better science in the future.

Let's focus our efforts on what is needed, not what is easy to obtain. A good example here is a lot of the data that we have collected on hatchery fish. I think Rich Carmichael said it very well when he cautioned us about extrapolating from results of studies on hatchery fish to what is going on with natural fish. Some of the information we need the worst may be the hardest to obtain. We must represent as clearly as possible what we actually know and do not know. Computer models are illustrative; they are not definitive; they do not tell us what is actually happening. The limitations to models lie in the biological assumptions built into the models and not just in the algorithms. Focus on those biological assumptions. Second, we must be careful that we are representing the precision of our studies well. Can we actually say that predator control fisheries removed 14% of the northern squawfish in the system this past year? I doubt it. We must be careful of overgeneralization. Beware of erroneous interpretations of what you say and what you write. A good example is the observation that northern squawfish eat mostly dead smolts in laboratory tests. People are starting to use this as a reason why predator control will not work. You have to be careful that you qualify what's going on, what your study is actually showing. Tony Nigro and Bruce Reiman have both countered this misconception quite well.

Fifth, correlation is not causation. We had good runs of fish in the later eighties. People working on specific salmon treaty implementations said, "Hey! It's working!" People working on changes in hatchery practices said those practices were working, based on the large runs. I would caution that you not take the short-term trend as an indication that what you're doing is working. Sixth, just because we have a need doesn't mean that the means exists to satisfy that need. This relates to what Teri Barila said earlier: Can we even research some of the black box areas that we need to know most about? We may not have the means of getting the answers, but we need to continue developing the tools to attain those answers. Scientists therefore must sometimes admit that we lack conclusive evidence.

Unfortunately, managers must make decisions even in the absence of good information. We don't have all that time in the world when stocks are going extinct. The time is past for relatively simple, relatively painless fixes. Earl Weber used a good analogy: "We've tried all the Band-Aids and they haven't worked." Doug Arndt points out, "It's not simply an either-or proposition. We're not looking for the single silver bullet." Chip McConnah, I think, summed it up the best, "Everybody is trying to grab for a simple solution, and they're always saying the problem is the other guy." We can't continue to throw away the great pool of talent, years of time, and millions of dollars in unproductive debate and processes. We as human beings, and especially in our western culture, tend to have a fixation on technology. This is expressed in many ways. It's expressed in the philosophy that we can manage better that nature itself can. We can harness the rivers, we can harness the watersheds, and if we have any problems arising from that, those can also be fixed. I refer to this as the Yankee ingenuity syndrome: where there's a will, there's a way; have faith, brother, we can all worship at the altar of high technology and everything will be all better in the end. In our arena of managing the fish, this Yankee ingenuity syndrome is often expressed as efforts to engineer the fish around the developments. Large-scale aquaculture programs may be seen as a technological fix to the problems, and so may fish transportation and retrofitting structural modifications on dams. All these are technical fixes, and they may not be adequate. It's time for a major redirection of our efforts.

BERT BOWLER: This forum has provided the opportunity for the majority of the scientists that are dealing with this issue to come together in a room for three days and kick it around, and for those funding this research to get some idea of what's really happening, what's going on, where the accomplishments are, and where the problems lie. I'll try to keep most of my comments relatively brief but I want to go back to just the intuitive sense of what we're really working with relative to moving anadromous smolts from the headwaters to the ocean and back. Reservoirs have slowed water passing through the projects, causing gas saturation problems, passage problems, and adult ladder problems within a pretty small range of the habitat these fish require to get to the ocean and back. If we could start over with a blank slate right now, how would we do it differently? How would we, with today's knowledge, redesign the system to make it compatible with hydro development and passage of fish up- and downstream? Another kind of exercise I would throw out concerns the cumulative impacts. Why don't we do an assessment of another project? Let's take a look at Asotin Dam. Could the systems support another project? Are we just seeing the cumulative impacts of eight hydroelectric projects catching up with us? I really think the unknowns and the uncertainty that Roy alluded to are largely related to cumulative impacts. There's no doubt in my mind that the chinook stocks today are testing positive for VIH, Victims of the Insidious Hydro system. They've been stressed to ultimate levels with increased travel times through the reservoirs, gas supersaturation, predation, turbine mortality, bypass mortality, spill mortality. This stress has pushed chinook stocks pretty much to the brink and that's where we're at in terms of the endangered species issue. We need to put in perspective what our goal is. In Idaho we look at it as a goal of returning productive stocks, of providing fishing opportunity. To return chinook stocks back to fishable numbers, we feel we'd need a smolt adult survival rate somewhere around 1%. We're dealing with returns now that are somewhat less than 0.1%. This just isn't cutting it.

I was impressed with Rock Peters' discussion about looking at bypass systems and how innovative we need to get. What we're really looking for is a hydro system that is much more flexible: Something that will pass smolts downstream and adults upstream readily over a range of 40,000 to 200,000 cfs. I think we're going to have bite the bullet in the face of uncertainty and make some radical changes to get there from here. We're going to have to get creative relative to balancing the mix between hatchery and wild fish, with hatchery production being a primary component of the harvest, and wild production being "genes in the bank," those genes that are going back to the wild areas as they've done for the last thousand years, and being able to utilize those to put back into the hatchery system.

FRED OLNEY: I think we've tried to cover a lot of ground in a very short time. There was new information presented here that has not been critically reviewed among the scientific community. I'd urge all of you who presented new data and analysis to write it up and get it off for formal review as soon as possible. I'd like to try to stimulate a little more discussion here this morning on some of the key technical points. With respect to the highly variable and protracted migration timing of wild spring and summer chinook, the concept of managing flow and spill within very restricted time periods or to protect just the middle 80% of the migration is obsolete. We have to provide safe passage conditions for the wild stocks moving through the system at all times. The information presented on fall chinook was very significant since it showed a bi-modal movement pattern of dispersal, followed by very protracted out-migration. I think the key issue of the effect of flow on travel time of subyearling chinook was not really presented completely and debated here within the last two days. It is my understanding that some of the modeling under way is assuming a constant travel time for fall chinook at all flow levels. I think it's important for the scientific communities to hear the rationale for that and to debate that issue.

On predation, I think the important question, which Tony and Roy and others have touched on, is how much of the predation is on fish that would die or have died in the reservoir from other causes, and how much is actual loss of healthy smolts to predation? It's going to be difficult to sort out quantitatively with any certainty, but the laboratory studies and field work on selective predation will help to further our understanding. Some of the comments have implied that predation is primarily a problem in the tailrace, but predation studies have shown that three out of four smolts consumed were eaten in the reservoir. I think the fact that northern squawfish eat dead fish is important, and I'm not saying that the predator removal tests that are under way are any less important. I think there's a high probability that a dead or dying smolt will end up in a squawfish stomach no matter where the location is in the reservoir. The work looking at naive hatchery fish vs. fish that have been exposed to predators is going to help to shed some further light on this. Northern squawfish are opportunistic predators and I think the hatchery fish could be serving as a buffer for predation on the wild stock. It's important to investigate that further. There's been a lot of discussion on the reach survival data, the Simms and Ossiander data. I would caution everyone to take a thorough look at it and evaluate all of the years for which that information was collected before drawing any conclusions. The inference has been made here that data based on just a few years is very suspect. I have a problem with reach survival estimates in that they are just that, an estimate of survival through a limited reach in the river and probably don't capture all of the impacts of passage through the hydro system. Fish condition was mentioned as a critical concern. We may have very good estimates of survival to the lower reaches of the river, but a lot of fish in poor condition don't make the transition to salt water, and that's a major limitation in these reach survival estimates. It's also a problem with the modeling. Jim Anderson mentioned that fish condition really hasn't been addressed in the mechanistic models. I think that's critical, and it's not surprising that the model currently doesn't predict the level of mortality in the low flow years of 1973 and '77 because the current mechanisms in the model are just predation and gas bubble disease. At low flows, the only way a fish dies in the model is from predation. Certainly fish condition must have had a lot of impact on fish survival in the low flow years in 1973 and '77.

RICHARD WHITNEY: Jim Congleton says I was invited here because I have experience on the mid-Columbia. Well, I don't think that was as valuable to me in evaluating what's happened over the last couple of days as my personal experience. My personal experience sort of represents a microcosm of what's going on in the Snake River, I think. You see, a couple of years ago I had a neighbor come up and dig a pond. And the next spring, the runoff filled up the pond and so I could see some underseeded habitat there. I decided to plant it with rainbow trout. So I engaged in some transportation. I went over to Soap Lake to a hatchery, got some hatchery rainbow trout, and brought them back. There were 166 of them to start with. There were no controls. I didn't want to leave any fish back there at Soap Lake, you know, that wasn't going to do me any good. So, pretty soon though the summer came on and the water level started to go down there. I said "Dick, we need some water. We need fish flush here." And so I had a well dug -- $10,000! You can imagine the reaction of the other half of our management team.

So, anyway, we got these fish. And after awhile I could see the numbers were declining. I was taking samples with barbless hooks, you know. And I figured that at one point I had about 12 fish left. I thought, "Well, I'm suspicious of my neighbor: he's probably over-fishing here." On the other hand, it might be a gas supersaturation problem because I was using well water and you know what can happen there. So, like I say this is a real microcosm of the Snake River situation.

Well, what about the last two days? My impression was that we're groping for answers. I was talking to Don Bevan about this yesterday, he started talking about the blind men and the elephant. I don't think that's what we've got here. This is more like we're turned loose in the shopping mall and the lights are out. We're groping around in there and we're feeling things and we're saying, "Hey, this is a spawning channel. This is good. Let's charge it on Aunt Bonnie's credit card." Then somebody else feeling around says "Here's a hatchery." So let's buy a bunch of those. Well, then a bypass, that's great of course, we'll take some of those. And then we got to habitat. I was surprised there, because I heard somebody say we don't need it. The Idaho people were saying something like, "Our habitat is fine. We have these wilderness areas. These cattle have run in these streams twenty years, nothing has changed. Our habitat is fine." And I'm saying, "Well, gee, you guys have forgotten about Stacy Gebhards 'cause he retired a number of years ago." I was at a meeting of the American Fisheries Society, a number of years ago now, where Stacy gave a talk on fish habitat in Idaho. And Stacy's solution to the problems in Idaho was to design a new fish. He even had a blue print for it. And he went ahead and built a model 'cause he showed us pictures of the model. The fish had wheels so it could get around in some of those Idaho creeks.

Well, transportation, of course, I've already talked about how I've used it and that's good. We had a little difference of opinion in some of the discussions on some of the data and its interpretation. Then the modelers get together to try and resolve some of this for us, and this is like somebody encountered the novelty shop, you might say. Here they come out with a gadget where you can break some eggs into a hat, and you pull out a beautiful white dove. Then I heard John Williams and some other people saying, "Wait a minute. We've been examining this skeletal structure of that critter and to us it looks more like a bumble bee, and it probably won't fly." Well, this is a shock. It's a pretty fragile creature that we've pulled out of this hat, anyway. That's my impression.

Then we get to flow. I think I liked what Al Giorgi was saying. What we really need is to be able to relate an increment of flow to an increment of animals that will be produced. I'm paraphrasing it, of course. So this is my real bottom line. We've got all these salesmen on duty in this darkened mall too, so we've got to listen carefully to the warranties that they offer. Seems to me what we really want to do in evaluating is to look at the number of fish that are going to be produced by each measure. Now, that's a pretty tough assignment for some of you, but that's what we really need to know in order to decide what would be an appropriate mix of all these things. I don't know that anybody has decided what an appropriate mix is yet.

We also have to recognize that Aunt Bonnie's credit card is limited. In fact I've heard that the Columbia Basin Fish and Wildlife Authority is at the point where funding of continuing projects pretty well limits any new proposals that might come in. So that means when they put the credit card in the cash machine, the message comes back "does not compute". So we're going to have to spend a little more time deciding on the appropriate mix.

Now, back to my own situation: I'm down to 12 fish. I think that may be a minimum critical population size and I've been thinking of filing an application for listing. I might be able to get some funds from another source--that remains to be seen. I think I could write a pretty good justification.